IEEE P650/D6-2005

(Revision of IEEE Std 650-1990)

Draft Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations

Sponsored by the
Nuclear Power Engineering Committee
of the
IEEE Power Engineering Society

Three Park Avenue
New York, New York 10016-5997, USA

This document is an unapproved draft of a proposed IEEE Standard. As such, this document is subject to change. USE AT YOUR OWN RISK! Because this is an unapproved draft, this document must not be utilized for any conformance/compliance purposes. Permission is hereby granted for IEEE Standards Committee participants to reproduce this document for purposes of IEEE standardization activities only. Prior to submitting this document to another standards development organization for standardization activities, permission must first be obtained from the Manager, Standards Licensing and Contracts, IEEE Standards Activities Department. Other entities seeking permission to reproduce this document, in whole or in part, must obtain permission from the Manager, Standards Licensing and Contracts, IEEE Standards Activities Department.

IEEE Standards Activities Department
Standards Licensing and Contracts
445 Hoes Lane
Piscataway, NJ 08855-1331, USA

Abstract: Methods for qualifying static battery chargers and inverters for Class 1E installations in a mild environment outside containment in nuclear power generating stations are described. These methods may also be used to qualify similar electronic equipment for use in mild environment applications outside containment, where specific standards for such equipment are not available. The qualification methods set forth employ a combination of type testing and analysis, the latter including a justification of methods, theories, and assumptions used. These procedures meet the requirements of IEEE Std 323, 2003, IEEE Standard for Qualifying Class1E Equipment for Nuclear Power Generating Stations. **Keywords:** battery charger, inverter, qualification.

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
445 Hoes Lane
P.O. Box 1331Piscataway, NJ 08855-1331
USA

IEEE Standards documents are adopted by the Institute of Electrical and Electronics Engineers without regard to whether their adoption may involve patents on articles, materials, or processes. Such adoption does not assume any liability to any patent owner, nor does it assume any obligation whatever to parties adopting the standards documents.

Foreword

(This Foreword is not a part of IEEE Std 650-2005, IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations.)

This standard provides the methods of qualifying class 1E static battery chargers and inverters in accordance with IEEE Std 323-2003, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations. The static battery chargers and inverters discussed in this standard are Class 1E. This document, however, addresses this equipment only as a subsystem in the safety related electrical system.

The techniques and information contained in this standard may be applied to other similar electronic equipment.

The guidelines of IEEE Std 381-1977, IEEE Standard Criteria for Type Tests of Class 1E Modules Used in Nuclear Power Generating Stations, have been utilized for aging complex electronic equipment. The reliability analysis requirements of IEEE Std 577- 2004, IEEE Standard Requirements for Reliability Analysis in the Design and Operation of Safety Systems for Nuclear Power Generating Stations, and the methods described in IEEE Std 352-1987, IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Station Protection Systems, have also been utilized along with statistical data.

The efforts of the working group on this standard and its appendixes will continue for the purpose of updating and disseminating more information regarding qualification techniques. The subjects of aging and the use of surveillance/ maintenance techniques to address aging will continue to be investigated, and will be among the areas considered by the working group in future revisions of this standard.

At the time this standard was approved, the Working Group on Battery Chargers and Inverters (2.13) had the following membership:

Dennis E. Dellinger, *Chair*
Kenneth Caldwell, *Secretary*
E.Reilly Schum

At the time that it approved this standard, the Qualification Subcommittee (SC-2) had the following membership:

Satish K. Aggarwal, *Chair*
Robert Lofaro, *Secretary*

Javier Alonso
Bohumil Bartonicek
Paul D. Baughman
Anup K. Behera
Brij Bharteey
Thomas Brewington
Nissen M.Burstein
Craig R. Butcher
Steve Casadevall
Suresh Channarasappa
Garry V. Chapman
Jeff Chivers
Sun Yeong Choi
James M. Dean
Liviu Nicolae Delcea
Dennis E. Dellinger
Philip DiBenedetto
Quang H. Duong
Frank Drumm
Artur J. Faya
Wells D. Fargo
Robert Francis
James F. Gleason
Patrick Gove
William L. Hadovski
Peter Helander
Thomas R. Hencey III
Jerrell C. Henley
David Horvath
Craig S. Irish
Serena A. Jagtiani-Krause
Mohsin Khan
Henry Leung
Bruce M. Lory
Darin R. Martin
P. G. McQuillan
Daniel R. Mikow
Todd Mitton
Asif Mohiuddin
Edward Mohtashemi
Carole Monchy-Leroy
Bill Newell
James Parello
Janez Pavsek
Daniel J. Pomerening
John M. Richards
Fred Roy
Steve Sandberg
Glen E Schinzel
Roderick Simms
Kjell Spang
Marek Tengler
Marco Van Uffelen
Laszlo Varga
Carl Weber
John Wheless
John White
Toni Wittamore
Richard T. Wood
Toshio Yamamoto

At the time that it approved this standard, the Nuclear Power Engineering Committee (NPEC) had the following membership:

TO BE INSERTED

When the IEEE Standards Board approved this standard on December XX, XXXX, it had the following membership:

TO BE INSERTED

CONTENTS

IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations

1. Scope and Purpose

1.1 Scope

This standard describes methods for qualifying static battery chargers and inverters for Class 1E installations in a mild environment outside containment in nuclear power generating stations. The application of this equipment in the plant's electrical system is not within the scope of this standard as other industry standards, such as IEEE Std 308–2001 [12][1], IEEE Std 603–1998 [21], and IEEE Std 946–1992 [23], exist for this purpose. In addition, industry standards exist for equipment performance, such as ANSI/NEMA PE 5–2003 [3] and IEEE 944-1986 [22]. Performance requirements are not specified in this standard.

1.2 Purpose

The purpose of this standard is to provide specific procedures to meet the requirements of IEEE Std 323–2003 [13]. For the purpose of this standard, battery chargers, inverters and the associated ancillary equipment must perform their safety function under specified service conditions.

The demonstration that an installed battery charger or inverter will meet its design specification requires many steps in a program of design, fabrication, quality assurance, qualification, transportation, storage, installation, maintenance, periodic testing, and surveillance. This standard treats only the qualification area of this program. The result of the qualification program may provide a basis for determination of long-term maintenance requirements.

Qualification may be accomplished in several ways: type testing, operating experience, or analysis. These methods may be used individually or in combination. The qualification methods in this standard employ a combination of type testing and analysis. Operating experience is of limited use as a sole means of qualification. Operating experience is, however, of great use as a supplement to testing, as the experience may provide an insight into the change in behavior of materials and components through time under actual service and maintenance conditions. Qualification by analysis shall include a justification of the methods, theories, and assumptions used. In general, battery chargers and inverters are too complex to be qualified by analysis alone, although analysis is effective in the extrapolation of test data and the determination of the effects of minor design changes to equipment previously tested.

---

[1] The numbers in brackets correspond to those of the references in Section 2

2. References

[1] ANSI/EIA 401–73 (R 79) (R 83) (R 90), Paper, Paper/Film, Film Dielectric Capacitors for Power Semiconductor Applications.[2]

[2] ANSI/EIA 454–78 (R 90), Fixed Paper and Film-Paper Dielectric Capacitors with Non-PCB Impregnants for Alternating Current Applications.

[3] ANSI/NEMA PE 5–2003, Utility Battery Chargers.[3]

[4] EPRI NP-3326, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components— Phase 1, December 1983.[4]

[5] EPRI NP-5024, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components— Phase 2, January 1987

[6] EPRI TR-106857V22, Preventive Maintenance Basis Volume 22: Inverters, December 1997

[7] EPRI TR-106857 –V23, Preventive Maintenance Basis Volume 23: Battery Chargers, December 1997

[8] EPRI TR-100491, NMAC UPS Maintenance and Application Guide, September, 1994

[9] IEEE Std 100–7th Edition, IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).[5]

[10] IEEE Std 101–1987, IEEE Guide for the Statistical Analysis of Thermal Life Test Data (ANSI).

[11] IEEE Std 259–1999 IEEE Standard Test Procedures for Evaluation of Systems of Insulation for Specialty Transformers.

[12] IEEE Std 308–2001, IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations (ANSI).

[13] IEEE Std 323–2003, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations (ANSI).

[14] IEEE Std 338–1987, IEEE Standard Criteria for the Periodic Testing of Nuclear Power Generating Station Safety Systems (ANSI).

[15] IEEE Std 344–1987, IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Generating Stations (ANSI).

[16] IEEE Std 352–1987, IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Station Protection Systems (ANSI).

[17] IEEE Std 381–1977 (Reaf 1984), IEEE Standard Criteria for Type Tests of Class 1E Modules Used in Nuclear Power Generating Stations (ANSI).

[18] IEEE Std 382–1996, IEEE Standard for Qualification for Actuators for Power Operated Valve Assemblies with Safety-Related Functions for Nuclear Power Generating Stations (ANSI).

---

[2] EIA publications are available from the Electronic Industries Association, Engineering Department, 2001 Eye Street NW, Washington, DC 20006, USA.

[3] NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

[4] EPRI reports are available from the Research Reports Center (RRC), P.O. Box 50490, Palo Alto, CA 94303, USA.

[5] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855–1331, USA.

[19] IEEE Std 383–2003 IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations (ANSI).

[20] IEEE Std 577–2004 (Reaf 1986), IEEE Standard Requirements for Reliability Analysis in the Design and Operation of Safety Systems for Nuclear Power Generating Stations (ANSI).

[21] IEEE Std 603–1998, IEEE Standard Criteria for Safety Systems for Nuclear Power Generating Stations (ANSI).

[22] IEEE Std 944-1986 IEEE Recommended Practice for the Application and Testing of Uninterruptible Power Supplies for Power Generating Stations

[23] IEEE Std 946–1992, Recommended Practice for the Design of Safety-Related DC Auxiliary Power Systems for Nuclear Generating Stations (ANSI).

3. Definitions

All definitions, except as specifically covered in this section, shall be in accordance with IEEE Std 100 7th Edition–[6].

battery charger: Equipment that converts ac power to dc power and is utilized to recharge and maintain a station battery in a fully charged condition and to supply power to dc loads during normal operation.

components: Items from which the equipment is assembled (e.g., resistors, capacitors, wires, connectors, semiconductors, tubes, switches, and electromechanical devices).

equipment: An assembly of components designed and manufactured to perform specific functions.

equipment qualification: The generation and maintenance of evidence to ensure that equipment will operate on demand to meet system performance requirements during normal and abnormal service conditions and postulated design basis events.
NOTE—Equipment qualification includes environmental and seismic qualification.

inverter: Equipment that converts dc power to ac power. Includes auxiliary devices such as transfer switches, alternate source transformers and regulators, input rectifiers (other than battery chargers), and isolation devices (e.g., blocking diodes).

margin: The difference between service conditions and the conditions used for equipment qualification.

mild environment: An environment that would at no time be significantly more severe than the environment that would occur during normal plant operation, including anticipated operational occurrences.

operating experience: Accumulation of verifiable service data for conditions equivalent to those for which particular equipment is to be qualified.

qualified life: The period of time, prior to the start of a design basis event, for which the equipment was demonstrated to meet the design requirements for the specified service conditions.

NOTE — At the end of the qualified life, the equipment shall be capable of performing the safety function(s) required for the postulated design-basis and post-design-basis events (IEEE Std 323–2003 [13]). In mild environments, Class 1E equipment may include components that have significant aging mechanisms. The qualification process will include information on when these aging mechanisms start, and any replacement/maintenance interval required.

4. Specifications

4.1 General

This section describes the items to be addressed in the owner’s specifications for the equipment to be qualified.

These items include the equipment identification, the Class 1E performance characteristics, the input power supply, the environmental conditions, and the effect of changes in input power supply and environmental conditions upon the Class 1E performance characteristics. If the equipment specification includes margins, as defined in Section 3, their values shall be identified.

4.2 Class 1E Performance Characteristics and Safety Function

The required Class 1E performance characteristics and the safety function shall be specified by those responsible for the design application of the equipment, and shall include, as a minimum, numerical values and durations for normal, abnormal, design-basis event (DBE), and post-design-basis event conditions, as indicated in 4.2.1–4.2.3.

4.2.1 Class 1E Performance Characteristics

1) Input conditions, such as
    a) Voltage
    b) Frequency
    c) Phase

2) Output requirements, such as
    a) Voltage and voltage regulation
    b) Current (minimum and maximum)
    c) Current limit
    d) Frequency and frequency regulation (inverters only)
    e) Load power factor (inverters only)
    f) Ripple voltage (battery chargers only)
    g) Harmonic distortion (inverters only)

3) Surge withstand capability
4) Reverse dc current flow prevention (chargers only)
5) Characteristics of auxiliary equipment (if used), including
    a) Transfer switches (functional operation, e.g., transfer time, high and low voltage actuation, and overcurrent actuation)
    b) Inverter's input rectifier (same input conditions as battery charger)
    c) Isolating device (blocking and conducting function)
    d) Alternate source transformer and regulator (input conditions and output requirements)

4.2.2 Description of the Safety Function of Class 1E Charger or Inverter

Defined by manufacture and purchaser.

4.2.3 Qualified Life Objective (where applicable)

Defined by manufacture and purchaser.

4.3 Environment

All significant environmental parameters shall be specified in the owner's specification. The range of environmental conditions shall include, as a minimum, normal and abnormal conditions and durations, as well as design-basis event and post-design-basis event conditions.

4.3.1

Where applicable, the equipment specification shall include numerical values for the magnitude and duration of the following service conditions:

1) Minimum and maximum, temperature including profiles if available.
2) Minimum and maximum storage temperature
3) Maximum relative humidity (operating and storage)
4) Altitude (static air pressure)
5) Operational vibration
6) Seismic requirements
7) Nuclear radiation type
8) Irradiation (dose rate and total dose)
9) Radio frequency interference (RFI) and/or electromagnetic interference (EMI) levels (i.e., the effects of the charger or inverter on other equipment, or vice versa)

4.4 Other Conditions

Where applicable, the equipment specifications shall include

1) Any significant rate of change or combinations of specified performance and environmental limits listed in 4.2 and 4.3
2) The expected total number of operating cycles or operating time period for the electromechanical devices (including periodic testing cycles)
3) Unusual atmospheric contamination (dust, oil, fungus, chemical or water spray, etc.)
4) Electrical and mechanical interfaces (e.g., input and output connections, mounting, voltages, currents, etc.)
    NOTE — As used in this document, interfaces are junctions between the Class 1E equipment to be qualified and other equipment or devices.
5) Dielectric test parameters

5. Qualification Methods

The qualification of Class 1E static battery chargers and inverters shall be determined by the qualification program outlined in this section. See Fig 1 for flow chart.

5.1 Analytical Requirements

An analysis shall be performed on all components within the charger or inverter to determine which components are required for the performance of its safety function and which components are not.

5.1.1 Nonsafety Component Analysis

A failure modes and effects analysis (FMEA) shall be performed, in accordance with Section 4.2 of IEEE Std 5772004 [20][6], on all components presumed to be nonsafety components. The FMEA shall demonstrate that the failure of these components, as used in the circuit throughout the qualified life of the equipment, does not affect the ability of the charger or inverter to perform its safety function (see 4.2.2) or, by way of interfaces, does not affect the safety functions) of other equipment. The nonsafety components shall be assembled into the sample equipment without additional analysis or testing. Any component whose failure is determined to affect the ability of the charger or inverter to perform its safety function by the FMEA shall be considered a safety component, and is addressed in 5.1.2.

5.1.2 Safety Component Analysis

Components designated as safety components are those, whose failure affects the ability of the charger or inverter to perform its safety function or, by way of interfaces, affects the safety function of other equipment. They shall be analyzed in accordance with the requirements of this section.

---

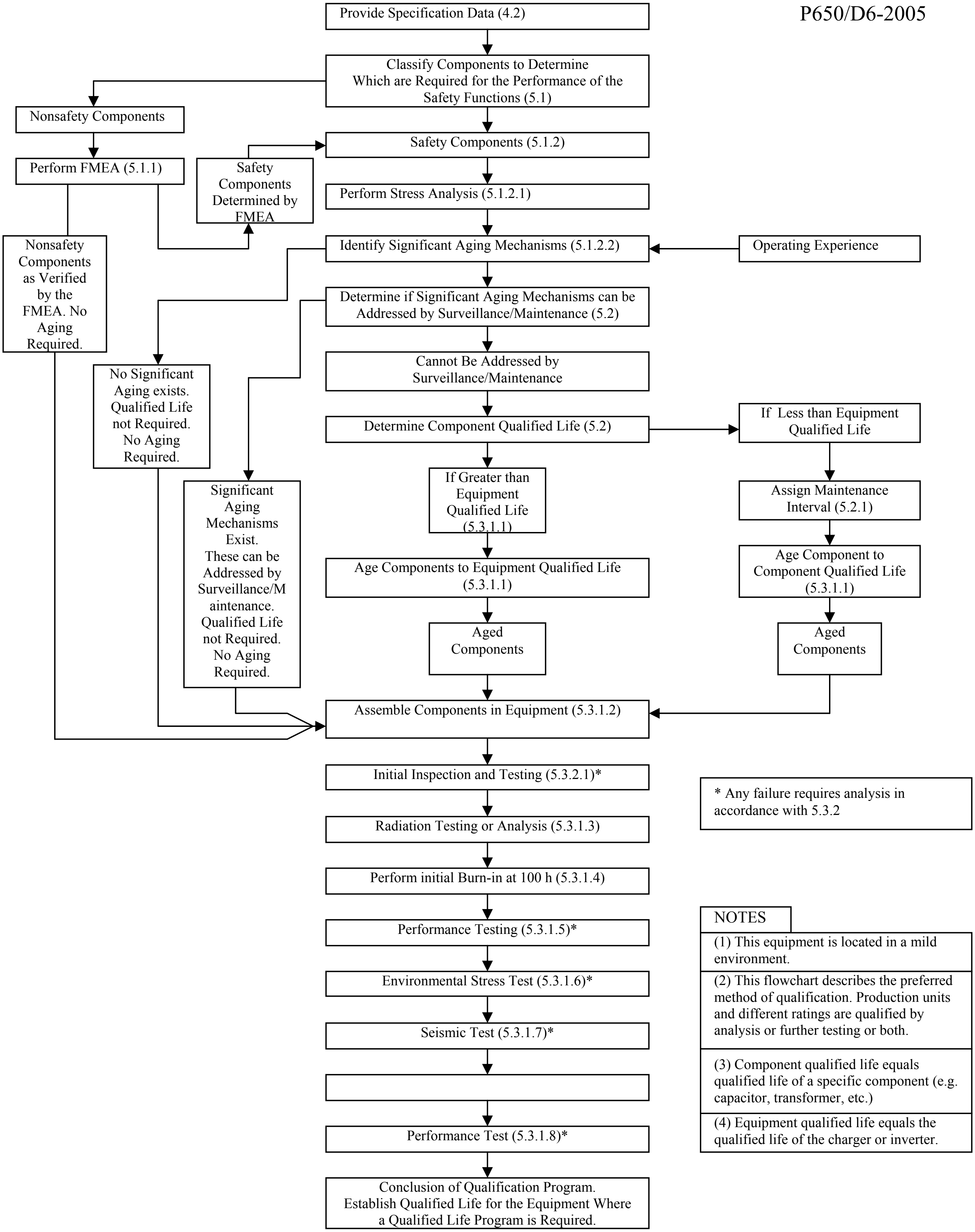
[6] For guidance in performing an FMEA, consult IEEE Std 352–1987 [16].

5.1.2.1 Stress Analysis

An essential part of the qualification of this equipment is to verify the integrity of its design. Thus, as part of the qualification process, a stress analysis of the equipment shall be performed to assure that no electrical component is stressed to a point where its aging is accelerated beyond that expected in operation. Should any components be overstressed, a redesign shall be performed to correct this condition. Appendix A provides background information on this topic, as well as an example of a stress analysis.

5.1.2.2 Component Classification

All safety components within the charger or inverter shall be classified as either components for which aging is not a significant failure mechanism or components for which aging is a significant failure mechanism. An aging mechanism is significant if, in the normal and abnormal service environment, it causes degradation during the installed life of the equipment that progressively and appreciably renders the equipment vulnerable to failure to perform its safety function(s) under DBE conditions (see Section 6.2.1 of IEEE Std 323–2003 [13]). Operating experience, testing, and analysis may be utilized in this classification process.



* Any failure requires analysis in accordance with 5.3.2

NOTES

(1) This equipment is located in a mild environment.

(2) This flowchart describes the preferred method of qualification. Production units and different ratings are qualified by analysis or further testing or both.

(3) Component qualified life equals qualified life of a specific component (e.g. capacitor, transformer, etc.)

(4) Equipment qualified life equals the qualified life of the charger or inverter.

Figure 1

Flowchart for Qualification of Class 1E Static Battery Chargers and Inverters

5.1.2.2.1

There is a significant amount of technical evidence available (see Appendixes B and C) that documents the effect of aging on the following components. If designed and manufactured with the same techniques used to manufacture the commercial grade equivalent of mil-spec components, and applied within their design rating (as determined by the stress analysis in 5.1.2.1), the aging effect is not significant within the qualified life objective of the equipment and within the typical mild environment radiation dose of 1.0E+03 rads.

For those components identified with a Φ, aging is not a significant failure mechanism, provided design and manufacture is performed with the same techniques and materials used to manufacture those components identified as exhibiting no difference in performance of unaged and aged components in EPRI NP-3326 [4] and NP-5024 [5]. Any differences between the specific components used in a charger or inverter and those identified in the EPRI reports must be justified.

NOTE — The symbol Φ as used in this section does not refer to activation energy.

1) Electronic components*
    a) Silicon semiconductors
    b) Surge suppressors — metal-oxide varistors and silicon type
    c) Resistors
    d) Tantalum dry electrolytic capacitors
    e) Ceramic capacitors
    f) Dry paper and plastic film capacitors
    g) Mica capacitors
    h) Glass capacitors
    i) Integrated microelectronic devices
    j) Hybrid microcircuits
    k) Φ Fuses
    l) Φ Control and instrument transformers and inductors
    m) Φ Control and instrument power supplies

2) Nonelectronic components.*
    a) Structural, nonwire insulating elements, and connections made of the following materials:
        1) Steel
        2) Aluminum
        3) Copper
        4) Epoxy/fiberglass laminates, NEMA Grade G-10 or G-11 equivalent
        5) Brass
        6) Ceramic
        7) Glass-filled diallyl phthalate
    b) Electromechanical components.* Aging is not a significant failure mechanism for certain specific types of the following electromechanical components in typical Class 1E battery charger or static inverter applications:
        1) Φ Connectors
        2) Φ Sockets (IC, Transistor, Relay)
        3) Φ Terminal Blocks made of the following materials:
            A) DAP
            B) Melamine
            C) Nylon
            D) Nylon 6.6
            E) Glass-filled phenolic
            F) General-purpose phenolic

        4) Φ Fuse blocks made of the following materials:
            A) Melamine
            B) X laminate

    C) Glass-filled polyester
    D) Phenolic
    E) Polycarbonate

5) Φ Meters
6) Φ Lamp sockets
7) Φ Electronic time delay relays
8) Φ Motors
9) Φ Circuit breakers (molded case)
10) Φ Relays (general purpose) — normally de-energized
11) Φ Snap acting switches

*Radiation tolerance levels must be verified by the manufacture/qualifier.

NOTE — Appendixes B and C furnish guidance for classifying additional components as those for which aging is not a significant failure mechanism.

Justification must be provided in order to classify components not meeting the above criteria as components without significant aging mechanisms.

5.1.2.2.2

Unless documentation showing that aging is not a significant failure mechanism can be provided, it shall be assumed that the following components have significant aging mechanisms:

1) Electromechanical components such as relays, fans, contactors, and circuit breakers
2) Insulated wire
3) Power magnetic components
4) Wet electrolytic capacitors
5) Surge suppressors (selenium)
6) AC oil-filled capacitors
7) Organic materials other than the non-aging, electromechanical components listed in Section 5.1.2.2.1 (2)(b) above

5.1.2.2.3

If components or materials other than the above are used, they shall be classified into one of the above groups (5.1.2.2.1 or 5.1.2.2.2). Classification into the group in 5.1.2.2.1 shall be justified. Justifications may be accomplished by operating experience, testing, or analysis.

5.2 Component Qualification

Components with significant aging mechanisms that can be addressed by periodic inservice surveillance/maintenance need not be aged prior to the type test. To qualify components with significant aging mechanisms that cannot be addressed by periodic inservice surveillance/maintenance, the component shall be aged to the equipment qualified life objective. If the qualified life of the component is expected to be less than that of the equipment, then the component shall be aged to its qualified life (prior to the type test) based upon either operating experience or component-life test data.

5.2.1 Determination of Maintenance Replacement Interval

The replacement interval for limited-life components that cannot meet the desired equipment qualified life shall be equal to or less than their qualified life. The qualified life of a component may be extended after installation by additional testing, analysis, or operating experience.

5.2.2 Aging Techniques

Components with significant aging mechanisms shall be aged in accordance with one or more of the following techniques.

5.2.2.1 Natural Aging

Components may be taken from a field installation that has been operating for the desired period designated as the component qualified life. Documentation shall be provided to demonstrate that the installed service conditions meet or exceed the specified service conditions.

5.2.2.2 Accelerated Aging

Accelerated aging is the process of subjecting a component or equipment to stress conditions, in accordance with known measurable physical or chemical laws of degradation, in order to render its physical and electrical properties similar to those it would have at an advanced age operating under expected service conditions. The following methods are recommended for accelerated aging of components where the component has not been exempted (see 5.1.2.2.1).

5.2.2.2.1 Circuit Breakers and Electromechanical Switches

The predominant age-related failure mode of circuit breakers and switches in typical Class 1E battery charger and static inverter applications is of a mechanical fatigue nature, as induced by switching cycles (Appendix D). However, an analysis of the materials employed in this device, in accordance with 5.1.2.2, is also required. Due to the continuous operating mode of this equipment, circuit breakers and control and power switches (and their associated annunciating relays) are cycled only during testing, preventive and corrective maintenance, and plant shutdown periods. A determination of anticipated maximum number of cycles [see 4.4 (2)] during the qualified life shall be made based on the sum of the following:

1) Number of cycles required for all necessary testing prior to plant operation
2) Estimated number of equipment maintenance cycles
3) Number of customer-planned cycles for any purpose (equipment or plant maintenance, etc.)

The breakers and switches shall then be cycled for the number of cycles determined above,. Coil-insulation systems associated with the breakers and switches shall be aged as described in 5.2.2.2.3.

5.2.2.2.2 Electromechanical Relays

The predominant age-related failure modes of electromechanical relays in typical Class 1E battery charger and static inverter applications are, as a result of fatigue, due to operating cycles and failure of the coil insulation system. The operating mode of each relay shall be identified as follows:

1) Normally energized — high-duty cycle (many times per day)
2) Normally energized — low-duty cycle (relay used during maintenance and testing, etc.)
3) Normally de-energized — high-duty cycle
4) Normally de-energized — low-duty cycle

The maximum expected number of operating cycles of each relay shall be determined for the equipment qualified life based upon the relay’s use in the equipment and the same criteria in 5.2.2.2.1. All relays shall be cycled under simulated service conditions for the number of cycles determined above,. The coil-insulation system shall be aged as described in 5.2.2.2.3. An analysis of the materials employed in these devices, as described in 5.1.2.2, is also required.

5.2.2.2.3 Magnetic Components

The life of magnetic components, as used in chargers and inverters, is determined by the insulation system (see IEEE Std 259–1999 [11]). An insulation system, on which thermal evaluation has been performed and correlated temperature versus age data has been established, shall be employed. Magnetic components shall be subjected to accelerated aging to the desired qualified life in accordance with Section 3.2 of IEEE Std 259–1999 [11].

5.2.2.2.4 Wire, Cable, Terminal Blocks and Connections

Insulated wire and cable shall be qualified for temperature, humidity, and time required for normal service of this equipment by the methods described in IEEE Std 383–2003 [19]. The basis for qualification shall include pre-aging data to simulate qualified life (such as Arrhenius plots with 95% confidence limits). Wire and cable insulation used in equipment units to be qualified by type testing shall be thermally aged in accordance with this data. Where practical, wire shall be aged in harnesses with connectors and terminal blocks attached, in order to test the integrity of the connection methods employed in the aged condition. When mechanical cycling of connectors can be shown to occur very infrequently, cycling need not be considered as an aging factor for qualification. Each type of connector and terminal block used in the equipment shall be included. Interconnections shall be tested through the thermal and mechanical stresses induced by the burn-in test (see 5.3.1.4), the stress test (see 5.3.1.6), and the seismic test (see 5.3.1.7).

5.2.2.2.5 DC Electrolytic Capacitors

Accelerated aging of dc electrolytic capacitors shall be achieved by subjecting the capacitors to rated core temperature and rated working voltage for the rated life or less. The rated life is the life published by the capacitor manufacturer when the capacitor is operated within rated conditions. The acceleration factors are obtained from the capacitor manufacturer’s curves that relate the ratio of rated working voltage and core temperature to actual operating working voltage and core temperature.

5.2.2.2.6 AC Oil-Filled Capacitors

Accelerated aging of ac oil-filled capacitors for sinusoidal voltage applications shall be achieved in accordance with the life data curves in ANSI/EIA-401-73 [1], and ANSI/ EIA-454-78 [2]. Capacitors subject to nonsinusoidal voltage, or other than 60 Hz (e.g., commutating capacitors), shall be aged as described above based upon the equivalent 60 Hz sinusoidal voltage.

5.2.2.2.7 Surge Suppressors

The protection of the power and control semiconductors against transient surges across the input and output of the equipment may be accomplished through the use of surge suppressors, transzorbs, mov’s, etc. The rate of aging of surge suppressors is determined primarily by the amount and duration of the applied current. The device passes current only when transient surges are encountered. The surge suppressors shall be aged by subjecting the device to the maximum number of surges anticipated during the qualified life. Unless otherwise required in the equipment specification, the device shall be subjected to 100 surges to simulate the qualified life. The surges shall be equal to or greater than those specified in 4.2.1 (3).

5.2.2.2.8 Circuit Board Assemblies

Circuit boards may consist of devices with significant aging mechanisms and devices without significant aging mechanisms. An analysis shall be performed of all components on the board to determine if any have significant aging mechanisms. If there are no components with significant aging mechanisms on the circuit board, it does not have to be aged prior to the type test. If there are components with significant aging mechanisms on the board that cannot be addressed by surveillance/maintenance, the component that has the shortest qualified life determines the qualified life of the board. All components with significant aging mechanisms shall be aged to the qualified life of the short-life component in accordance with the aging techniques in this section. These components may be aged on or off the circuit board. If aged off the board, care shall be taken to avoid damaging the components during assembly onto the board.

5.2.2.2.9 Fuses

Fuses in Class 1E battery chargers and inverters are used to protect semiconductors, instrumentation, and power and control circuits. Fuses shall be properly applied in circuits with respect to ampacity, voltage, and temperature. Specifically, an adequate temperature margin shall be provided to preclude an increase in temperature rise at the fuse or fuse holder termination beyond the fuse rating. Documentation may be provided to verify that the fuses are properly applied in the circuits with respect to ampacity, voltage, and temperature, and that adequate temperature margin has been provided to preclude an increase in temperature rise at the fuse or fuse holder termination beyond the fuse rating. If such documentation is provided, there are no age-related common-mode failure mechanisms for the fuses used. If this documentation is not available, this device may be aged by natural or accelerated methods.

5.2.2.2.10 Organic Materials

Arrhenius plots (see IEEE Std 101-7th Edition [9]) may be used to develop accelerated thermal aging techniques for the organic materials to be qualified. If Arrhenius plots do not exist for certain materials, an activation energy of 0.8 eV should be used as a conservative and technically justifiable value.

5.2.2.11 Motors, Pumps and/or other components.

Motors, pumps and/or other components may consist of materials with significant aging mechanisms. An analysis shall be performed on all materials to determine if any have significant aging mechanisms. If a component has no materials with significant aging mechanisms, it does not have to be aged prior to the type test. If a component has materials with significant aging mechanisms that can not be addressed by surveillance/ maintenance, the component shall be aged in accordance with the aging techniques in this section. The material that has the shortest qualified life determines the qualified life of the component.

5.3 Equipment Qualification

Section 6.3.1.7 of IEEE Std 323–2003 [13], outlines a sequence in which type testing may be performed. For equipment with components with significant aging mechanisms that cannot be addressed by surveillance/maintenance techniques, this sequence is not followed in this standard, due to the variation in aging rates of the components. Since the equipment is to be assembled of aged components, testing of the sample equipment must come after the components have been aged and the assembly is complete. The type test sequence in this section is conservative in that the components are subjected to additional stresses after aging. With the inclusion of the seismic test, this conservatism is sufficient to account for reasonable uncertainties in demonstrating satisfactory performance and normal variations in commercial production, and thus assure that the equipment can perform under the most adverse condition specified.

5.3.1 Type Test

The type test sequence shall be conducted as follows.

5.3.1.1

Components shall be analyzed and, where required, aged to their respective qualified life or the equipment qualified life, whichever is less, in accordance with 5.2.

5.3.1.2

New (nonaged) and age-conditioned components shall be assembled into a complete piece of equipment in accordance with applicable production procedures. Mechanical inspection, dielectric testing [see 4.4 (5)], and functional testing for normal conditions (see 4.2) shall be performed. When applicable the ability of the equipment to operate within the levels of RFI/ EMI specified in 4.3.1 (9) shall be demonstrated by analysis, testing, or both.

5.3.1.3

Since the battery charger or inverter is located in a mild environment, only low levels (typically less than 1.0×10^3 rads, total integrated dose) of radiation are encountered. Documentation (analysis or testing) shall be provided to demonstrate that the ability of the equipment to perform its required function is unaffected by the radiation dose specified in 4.3.1 (7 and 8).

5.3.1.4

The equipment shall be subjected to minimum burn-in of 100 h (50 h at full load, 50 h at minimum specified load) at room ambient temperature. The burn-in places the equipment into its normal installed condition and is intended to eliminate infant mortality failures.

5.3.1.5

In order to establish a reference for the measurement of operating parameters and a valid basis for the comparison of test results, the complete equipment shall be subjected to the conditioning process as follows.
Place the equipment in an environmental test chamber that has the capability of being varied both in temperature and humidity over the required service conditions. With the chamber set at an ambient temperature of 25 ° C ± 5 ° C and prevailing relative humidity, operate the equipment at full load for a period of 2 h, and document functional performance data for normal conditions [see 4.2.1 (1 and 2)(a, b, and d,]. This data shall be analyzed for conformance to the Class 1E performance characteristics and utilized as reference data for the continued tests to follow. Calibration adjustments may be made to the equipment at this time.

5.3.1.6

In order to demonstrate that the equipment will meet its specified Class 1E performance characteristics under the specified service conditions (as required by IEEE Std 323–2003 [13]), refer to Fig 2 and perform the following stress test to the fully loaded equipment in the test chamber.

1) Allow the chamber to increase to the maximum temperature and maximum relative humidity specified in the service conditions (see 4.3). The equipment shall be operated at this level for a period of 8 h, at the end of which functional performance data [see 4.2.1 (1 and 2)(a, b, and d)] at maximum, nominal, and minimum input voltages, and maximum and minimum loads shall be documented.
2) Allow the chamber to decrease to the minimum temperature specified in the service conditions (see 4.3) and maximum obtainable relative humidity (50% minimum). The equipment shall be operated at this level for a period of 8 h at the end of which functional performance data [see 4.2.1 (1 and 2)(a, b, and d)] at maximum, nominal, and minimum input voltages, and maximum and minimum loads shall be documented.
3) A complete cycle, including the transition period, shall last a maximum of 36 h. At the end of the test cycle, the equipment shall be allowed to stabilize at room ambient temperature and humidity, and a final set of functional performance data [see 4.2.1 (1 and 2)(a, b, and d)] at maximum, nominal, and minimum input voltages, and maximum and minimum loads shall be documented. The above stress test is described in Fig 2.

This test subjects the complete equipment to the worst-case and nominal conditions of temperature, humidity, input voltages, and output loads (input frequency variations have no impact on stressing the equipment).

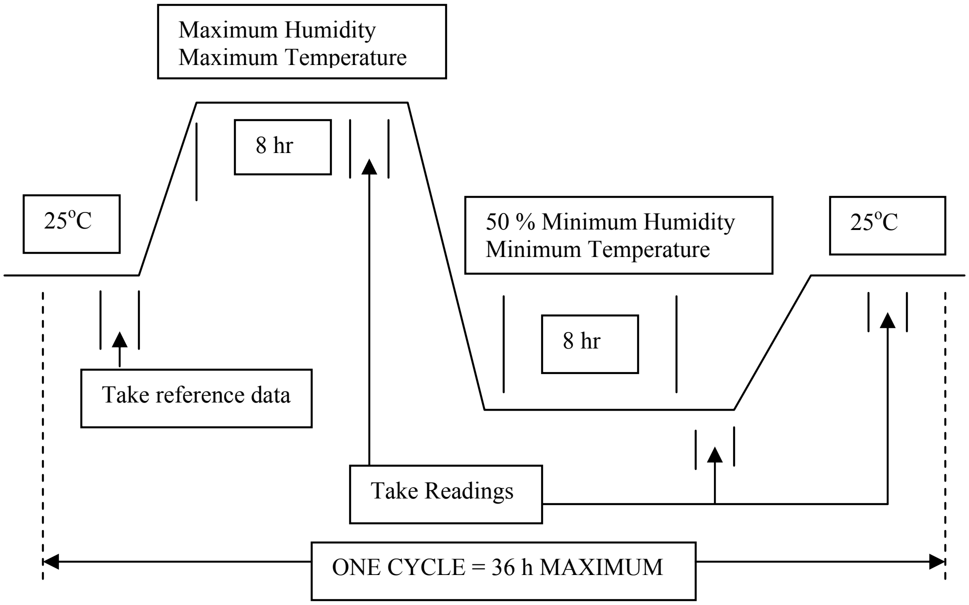


Figure 2
Stress Test

5.3.1.7

The ability of the equipment to withstand the operational vibration requirements specified in 4.3.1 (5) shall be demonstrated by analysis, testing, or both. Since this equipment is located in a mild environment, seismic is the only design-basis event (DBE) of consequence. The equipment shall therefore be seismically qualified according to IEEE Std 344-1987 [15]. The seismic acceleration levels shall include, as a minimum, +10% for margin for SSE test (see Section 4.1). If tested, the equipment shall be operated during and after the seismic test at rated output and specified input voltage.

5.3.1.8

Upon successful completion of these tests, a functional test shall be performed to meet the Class 1E performance requirements for normal conditions specified in 4.2, and the equipment shall be considered qualified.

5.3.2 Acceptance Criteria

Should any failure occur during test steps 5.3.1.2, 5.3.1.3, or 5.3.1.4. the defective component shall be replaced with a component that has been subjected to the same aging as the component that it replaces. In the evaluation of the type test results, any sample equipment is considered to have passed when the equipment meets or exceeds the function required by the equipment specification (see Section 4).

Any failure occurring during the testing and qualification process shall be analyzed to determine if it is of random or common cause origin. The failure shall be determined not to be of common cause origin if one of the following criteria is met:

1) Physical examination of the failed component(s) and its interface(s) determines that a random workmanship problem was the cause of failure.
2) Reexamination of the stress analysis determines that the part is properly applied and any components similarly applied in the test sample have had no like failures and the failure is not repeated during subsequent retesting with replacement components.

NOTE — For purposes of this standard, consequential component failures caused by the failure of a single component are not considered to be of common cause origin.

If the above or other methods have not identified the cause of failure, further analysis must be conducted.

If a failure is determined not to be of common cause origin, the equipment shall be repaired with replacement components that have been subjected to the same aging as those that it replaces (see 5.2). If the type test is continued, then it shall commence at the beginning of the specific test during which it failed.

If a failure is determined to be common cause (either age-related or stress-related), the equipment shall be rejected. Qualification of the equipment may be attained by redesigning, modifying, and retesting as above, or qualifying for less stringent conditions by retesting to lower parameters (e.g., shorter qualified component or equipment life, or lower seismic values).

5.4 Qualification of a Product Line

It is possible to qualify a product line (that is, chargers or inverters of a similar design of assorted ratings) by utilizing all of the following techniques:

1) Perform a type test on a sample equipment in accordance with 5.3.1.
2) Perform a complete analysis of components of the other model ratings, in accordance with 5.1, to demonstrate that no component of the type aged and qualified in the type tests is stressed at a rate higher than that in the qualified model, to the extent that a different aging acceleration would have to be employed. Should the analysis determine that either a different aging acceleration test is necessary or an entirely new generic type of part be employed, the part shall be aged and seismic tested as a component or assembly to a level equivalent to the previous qualification level. NOTE — Different ratings of the same component family are considered type-qualified if the applied stress does not exceed that in the qualification model.
3) Verify that the service conditions to which the qualified unit was tested are at least as severe as those specified of the unit being qualified.
4) Each model rating shall be seismically qualified by testing or analysis, or both, in accordance with IEEE Std 344-1987 [15] and a determination shall be made that the acceleration of components or assemblies does not exceed that of the qualified model.

5.5 Extension of Qualified Life

The methods described in Section 6.3.5 of IEEE Std 323–2003 [13] are applicable for extending the qualified life of Class 1E static chargers and inverters.

6. Documentation

6.1 General

The following documents are required to verify that the Class 1E static battery charger or inverter is qualified for its application, meets the specification requirements of Section 4, and has its qualified life or periodic surveillance/ maintenance interval established.

6.2 Qualification Plan

The qualification plan shall contain a description of the methods and procedures used to qualify a particular Class 1E static charger or inverter for a specific application. The plan shall contain the following:

1) Identification of the equipment to be qualified, including mounting and interface requirements if applicable
2) Qualification procedures applicable to the equipment to be qualified
3) Details on the differences between the equipment to be qualified and equipment that is type tested, and the methods used to justify those differences

4) Description of the acceptance criteria for the equipment to be qualified
5) Description of the safety function of the equipment to be qualified
6) Where applicable, the qualified life objective of the equipment to be qualified

This plan is generally submitted to the purchaser for approval and to ensure consistency between the type-tested equipment and the equipment to be qualified.

6.3 Qualification Report

The qualification report shall contain the following:

1) Equipment Specifications (see Section 40
2) Identification of specific features to be demonstrated by the analysis and testing
3) Qualification plan (see 6.2)
4) Qualification results, which shall include:
    a) Failure modes and effects analysis (FMEA) for nonsafety related components, if applicable (see 5.1.1).
    b) Stress analysis (see 5.1.2.1).
    c) Documentation for classification for component qualification (5.1.2.2).
    d) Identification of any scheduled surveillance/maintenance, periodic testing, and any parts replacement required to maintain qualification.
    e) Test data, aging data (where applicable) for age sensitive components, accuracy and instrument calibration for each test described in 5.3.1. A seismic test report or analysis shall be furnished.
    f) Documentation for radiation analysis or test (see 5.3.1.3).
    g) Analysis for any failure or anomaly occurring during the qualification type test.
    h) Any shelf life requirements.
    i) Where applicable, identification of equipment qualified life with a summary of justification for the qualified life.
    j) Where applicable, extension of qualified life data.

6.4 Qualification of Product Line

The qualification report (see 6.3) may provide a basis for qualifying Class 1E static battery chargers and inverters of various sizes and ratings. Documentation shall be provided which verifies that such analysis is performed in accordance with 5.4.

6.5 Additional Documentation Requirements

1) *Certificate of compliance*. A certificate of compliance that certifies that the equipment supplied meets the requirements of the owner’s specification is required.
2) *Approval signature and date*. Each of the above documents shall include an approval signature and date.
3) *Qualification report*. The qualification report shall include, in addition, the approval signature of an independent reviewer and date.

Annex A Stress Analysis

(Informative)

A1. Introduction

This Appendix outlines a stress analysis procedure and provides an example for performing the stress analysis required by 5.1.2.1. Other procedures, if properly justified, may be used.

A2. Objectives

The primary purpose of the stress analysis, as part of the qualification process, is to ensure that no component is stressed to a point where its aging is accelerated beyond that in expected service conditions. The stress analysis will indicate where redesign is required for any overstressed components. In addition, the stress analysis will provide a data base for generic product line qualification, enabling a direct design comparison of other ratings with that originally qualified.

A3. Definitions

stress analysis: An electrical and thermal design analysis of component applications in specific circuits under the specified range of service conditions.

A4. Procedure

A4.1 Analysis

An electrical, thermal, and part-stress analysis of the components of each charger or inverter to be qualified should be performed in accordance with MIL-HDBK-217E-1986, Reliability Prediction of Electronic Equipment (see B3.2).

1) For stress analysis to be valid, manufacturer's ratings should never be exceeded.
2) Semiconductors should be analyzed for both thermal and voltage stress.
3) Capacitors should be analyzed for voltage stress.
4) Resistors should be analyzed for thermal stress.
5) Fuses should be analyzed for voltage and thermal stress.

The stress analysis should be performed, assuming an ambient air-inlet temperature of 25 ° C, or the maximum, plus the worst-case internal temperature rise for the inverter or charger (normally, 5 ° C–10 ° C). Design information should be obtained from the charger or inverter schematic drawings, assembly drawings, list of materials, parts catalogs, and data sheets.

The analysis method described above consists of determining electrical stress, thermal stress, and failure rates of system components based on the proper selection and use of each component and the environment in which the equipment is to be used.

Stress analysis should be performed in accordance with Section 5.1 of MIL-HDBK-217E-1986 (see B3.2).

A4.2 Calculations

In performing the electrical stress analysis, each circuit in the charger or inverter should be analyzed in detail. Equivalent circuits may be used to determine loop currents and node voltages. From these currents and voltages, applied stress can be obtained. All stress calculations should be made in accordance with the methods outlined in MIL-HDBK-217E-1986 (see B3.2). The stress ratios are defined as follows:

For semiconductors:

$$\text{stress ratio} = \frac{\text{wattage applied}}{\text{wattage rated}}$$

$$\text{stress ratio} = \frac{\text{volts applied}}{\text{volts rated}}$$

For resistors:

$$\text{stress ratio} = \frac{\text{wattage applied}}{\text{wattage rated}}$$

See Appendix B3. for the minimum applied stress ratios.

Table A.1

Sample Stress Analysis Data Sheet

System: INV 253-1-101 Assembly. DC-DC Converter Board

Reference Designation	Component	Value	Description or Part Number	Specification	Stress		Stress Ratio	Quantity
					Rated	Applied		
CR122	SiDIODE, RECT		1N4004	MILS-19500	IA	<0.1A	0.1	1
CR123	RECT		1N4004		1A	<0.1A	0.1	
CR124	RECT		1N4004		1A	<0.1A	0.1	
CR125	VR		1N5352B		5W	0.27W	0.1	
CR126	RECT		1N4004		1A	0.2A	0.2	
CR127						0.2A	0.2	
CR128						0.2A	0.2	
CR129						<O.1A	0.1	
CR130	RECT		1N4004		IA	<O.1A	0.1	
CR131	VR		1N7534		**400mW**	55mW	0.2	
CR132	SIG		1N914		75mW	<imA	0.1	
CR133	RECT		1N4004		1A	<0.1A		
CR134								
CR136								
CR136								
CR137	RECT		1N4004		1A	<0.1A	0.1	
CR138	VR		1N5352B		6W	0.57W	0.2	
CR139	SiDIODE, VR		1N5352B	1111S-19500	5W	0.57W	0.2	1
BRIM	SiDIODE, R BRIDGE		MDA990-3			1.5A	0.1	1x4

Temperature: 35 °C Environment: GF

Table A.2

Sample Stress Analysis Data Sheet

System: INV 253-1-101

Assembly. DC-DC Converter Board

Reference Designation	Component	Value	Description or Part Number	Specification	Stress		Stress Ratio	uantity
					Rated	Applied		
R122	RESISTOR, CC	10 kit	RC20	MILR-11	500 mW	17 mW	0.1	1
R123	MF	162 kit	RN60	MILR-10509	125 mW	60 mW	0.5	
R124	**MF**	13.7 kit	RN6O	MILR-10509	125 mW	7mW	0.1	
R125	cc	1 kit	RC20	MILR-11	500 mW	80 mw	0.2	
R126	CC	1 kit				3mW	0.1	
R127		100 kit				2 mW	0.1	
R128		2.2 kit				90 mW	0.2	
R129		470 kit				8 MW	0.1	
R130	CC	10 kit	RC20	MILR-11	500 mW	20 mW	0.1	
R131	**W W**	0.68 i2	C W 5	MIL-R-26	5 W	0.68 W	0.2	
R132	**W W**	0.68 i2	CW5	MILR-26	5 W	0.68 W	0.2	
R133	**W W**	0.68 i2	C W 5	MILR-26	5 W	0.68 W	0.2	
R134	Ct	1 kit	RC20	MIL-R-11	500 mW	4mW	0.1	
R135	CC	39012	RC42	MILR-11	2 W	0.58 W	0.3	
R136	CC	470f1	RC20	MIL-R-11	500 mW	20mW	0.1	
R137	RESISTOR, W W	i ki2	CW10	MILR-26	low	2.5 W	0.3	1

For capacitors:

$$\text{stress ratio} = \frac{\text{volts applied}}{\text{volts rated}}$$

Finally, the stress correction factor for each semiconductor device should be determined based on maximum junction temperature T_m and operating temperature T_s.

$$\text{Stress correction factor } (CF) = \frac{T_{max} - T_s}{150}$$

Component stress should be calculated assuming that all possible modes of circuit operation may be used continuously. Worst-case operating mode conditions should be used. Since worst case cannot occur for all components simultaneously, the result of the analysis will be conservative.

A4.3 Stress Analysis Data

The results of the stress analysis should be tabulated in a form similar to that shown in Tables A.1 and A.2. These stress analysis data sheets should list all system electrical components by assembly or printed circuit board, or both. Components should be arranged by type and circuit application. Identical components utilized such that identical maximum stress occurs, may be listed together by symbol numbers in the first column, yielding a part quantity. The component MIL style designations are listed along with a brief description, permitting identification. Where MIL designations are not available, the accepted industry type or company source control drawing should be listed. Capacitor values are listed in µ F and pF. Resistors values are in Ω , and stress is in mW, unless otherwise noted.

Annex B Electronic Components for Which Aging is Not a Failure Mechanism

(Informative)

B1. Introduction

Aging is not a significant failure mechanism for certain electronic components in typical Class 1E static battery charger and inverter applications.

When applied within their design rating, the aging of electronic components occurs at such a low rate that its effect on failure rate is undetectable. Silicon-base semiconductors, for example, never wear out if constructed and used according to specifications. All semiconductors, however, contain manufacturing imperfections (e.g., at the bonding junction) that eventually cause failure. Most devices have only slight imperfections that allow a lengthy service life. About one percent have defects that cause early infant mortality failures. The burn-in requirement is used to eliminate as many of these devices as possible.

B2. Failure Rate History for Components

To illustrate the failure rate history of these electronic components, refer to Fig B.1. This bathtub curve has three characteristic sections. The first section reflects a high failure rate due to early failures of weak or defective components. The components are not representative of the longevity of the others, and are usually eliminated from use by subjecting the sample to a preliminary period of operation, often referred to as a *burn-in period*. During this period, the initially high failure rate will continue to decrease until it reaches a value for which it remains relatively constant with respect to time. The burn-in period is of short duration, typically 30–100 h. The second section of the failure-rate time history curve represents the random failure-rate value of the component sample where none of the systematic failure mechanisms are operating, such as early defects or wearout failures. The duration of this section is several thousand times as long as the burn-in period. The third section of the bathtub curve is the beginning of the wearout failure mechanism for the component. Since the desired equipment qualified life falls within the area of the curve in which the electronic component failure rate is constant, the failure rate of a new (burned-in) component is essentially equal to the failure rate of a component aged to the equipment qualified life. That is, the wearout period for electronic components falls beyond the equipment qualified life.

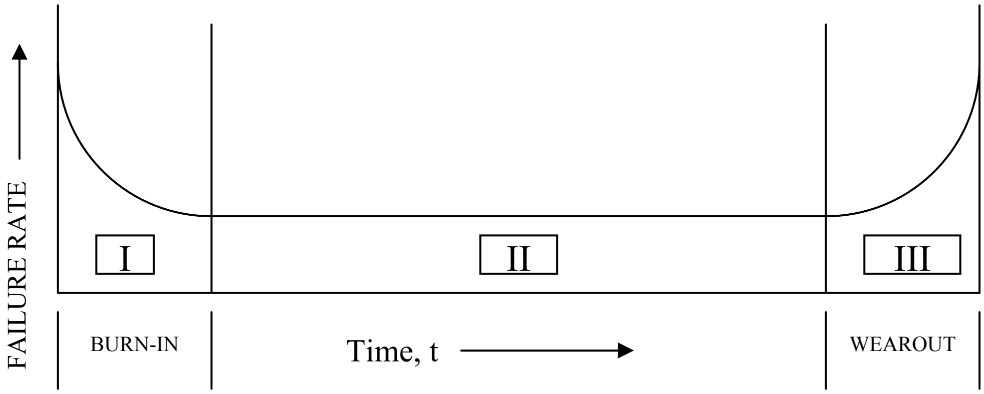


Figure B.1

Failure Rate History for Components, in Percent

While it is true that extended extremes of temperature and humidity can alter this non-aging characteristic, this Appendix applies only to applications in a mild environment, where the temperature and humidity will remain within the specified service conditions. Thus, aging within the qualified life period is not a significant failure mechanism.

B3. Bibliography — Electronic Components

An extensive bibliography has been assembled to justify the non-aging concept presented here.

NOTE — References that contain specific conclusions that support the non-aging concept are followed by an asterisk.

B3.1 Non-aging Concept for Electronic Components

EPRI NP-3326, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components — Phase 1, December 1983.*

EPRI NP-5024. Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components — Phase 2, January 1987*

Balaban, H. “Some Effects of Redundancy on System Reliability.” Sixth National Symposium on Reliability andQuality Control in Electronics, Washington, DC, Jan. 1960.

Best G. E., Bretts, G. R., McLean, H. T., and Lampert, H. M. “Determination Application of Aging Mechanisms Datain Accelerated Testing of Selected Semiconductors, Capacitors, and Resistors.” National Symposium on Reliability and Quality Control, 1965, pp. 293-302.*

Davis, D. J. “An Analysis of Some Failure Data.” Journal of the American Statistical Association, vol. 47, no. 258, Jun. 1952.

Flehinger, B. J. “Reliability Improvement Through Redundancy at Various System Levels.” IBM Journal of Research and Development, vol. 2, Apr. 1958.

Hahn, G. J., and Nelson, W. “Comparison of Methods of Analyzing Censored Life Data to Estimate Relationship between Stress and Product Life.” *IEEE Transactions on Reliability*, vol. R-23, no. 1, Apr. 1974.*

Henney, K. (ed). *Reliability Factors for Ground Electronic Equipment*. New York: McGraw-Hill Book Co., Inc.,1956.

Jones, E. R. *A Guide to Component Burn-In Technology*. Wakefield Engineering, Inc., 1972.

Kahn, H. and Mann, I. “Techniques of System Analysis,“ Rand Corporation, Research Memorandum RM-1829–1, Jun. 1957.

Mann, N. R., Schafer, R. E. and Singpurwalla, N. D. *Methods for Statistical Analysis of Reliability and Life Data.* New York: John Wiley and Sons, Inc., 1974.*

Mine, H. “Reliability of Physical Systems.” *Transactions of the 1959 International Symposium on Circuit and Information Theory*, IT-5, special supplement, May, 1959.

Moskowitz, F. “The Analysis of Redundant Networks.” *Communications and Electronics.* no. 39, Nov. 1958.

Reliability Stress Analysis for Electronic Equipment. Technical Report TR-59-416-1, RCA, Camden, NJ, Jan. 1959.

Smith, W. L. “Renewal Theory and its Ramifications.” *Journal of the Royal Statistical Society*, series B, vol. 20, no. 2, 1958.

B3.2 Silicon Semiconductors

The statements made in the references below are based upon actual test data on Mil-Spec as well as commercial grade components. This bibliography does not require that Mil-Spec components be used, as long as they are components that have been manufactured using the same techniques as those used to manufacture the equivalent Mil-Spec components. For the purpose of this document, Joint Electron Device Engineering Council (JEDEC)[7] components are considered to be acceptable commercial grade equivalent Mil-Spec components.

EIA Recommended Standard RS-313-B, Thermal Resistance Measurements of Conduction Cooled Power Transistors. Oct. 1975.

EPRI NP-3326, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components—Phase 1, Dec. 1983.*

EPRI NP-5024. Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components—Phase 2, Jan. 1987.*

MIL-HDBK-217E-1986, Reliability Prediction of Electronic Equipment.*[8]

NOTE — This document contains an extensive bibliography.

Gallance, L. “Quantitative Measurement of Thermal Cycling Capability of Silicon Power Transistors.” RCA Application Note, AN-6163.

Grove, A. S. *Physics and Technology of Semiconductor Devices.* New York: John Wiley and Sons, Inc., 1967, pp. 201–205.

Kemenyk, A. P. “Experimental Investigation of the Life of Semiconductor Devices I. Accelerated Life Tests of Transistors Under Static Electrical Load and at High Temperature Storage.” ACTA Technical Academy of SCI, Coden: ATSHA8, Hungary, vol. 74, no. 1–2, 1973, pp. 85–144.*

Kuno, H. J. “Analysis and Characterization of PN Junction Diode Switching.” *IEEE Transactions on Electron Devices*, Jan. 1964, p. 8.

Lang, G. A., Fehder, B. J., and Williams, W. D. “Thermal Fatigue in Silicon Power Transistors.” *IEEE Transactions on Electron Devices*, Sept. 1970.

Lukach, V. J., Gallance, L., and Williams, W. D. “Thermal Cycling Ratings of Power Transistors.” RCA Application Note, AN-4783.

Miller, L. E. “Reliability of Semiconductor Devices for Submarine Cable Systems.” *Proceedings of the IEEE*, 62, no. 2, Feb. 1974, pp. 230–244.*

Oettinger, F. F., Blackburn, D. L., and Rubin, S. “Thermal Characterization of Power Transistors.” *IEEE Transactions on Electron Devices*, vol. ED-23, pp. 831–838, Aug. 1976.

Oettinger, F. F., and Rubin, S. “The Use of Current Gain as an Indicator for the Formation of Hot Spots Due to Current Crowding in Power Transistors.” *Proceedings of the IEEE Reliability Physics Symposium*, Las Vegas, Nevada, Apr. 5, 1972.

---

[7] Joint Electron Device Council, 2001 Eye Street NW, Washington, DC 20006, USA.

[8] MIL documents are available from the Commanding Officer, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120, USA.

Ower, P. L., Westinghouse Research Labs, Blackburn, D. L., Oettinger, F.F., and Rubin, S. National Bureau of Standards. “Stable Hot Spots and Second Breakdown in Power Transistors.” IEEE Power Electronics Specialists Conference, 76CH1084-3AES, 1976, p. 234.

Ravi, K V. “Reliability Improvement of 1 Mil Aluminum Wire Bonds for Semiconductors.”Motorola Inc., Contract NAS8-26636, Dec 1971.

Reynolds. F. H. “Accelerated-Test Procedures for Semiconductor Components. Post Office Research Center,”Martlesham Heath, Ipswich, IPS7RE, England.*

NOTE — This paper contains an extensive bibliography.

Schmid, E. R. “How to Eliminate Premature Semiconductor Failures.”*Machine Design*, Aug. 25, 1977.*

Von Zastrow, E. E. and Galloway, J. H. “Commutation Behavior of Diffused High Current Rectifier Diodes.”*IEEE Transactions on Industry and General Applications*, vol. IGA-1, no. 2, Mar./Apr 1965, pp. 157–166.

Wahl, A. J. “Ten years of Power Aging of the Same Group of Submarine Cable Semi-conductor Devices.”*Bell Systems Technical Journal*, vol. 56, no. 6, Jul./Aug. 1977, pp. 987–1005.*

Wahl, A. J., McMahon, W., Lesh, N. G., and Thompson, W. J. “SF System: Transistors, Diodes, and Components.”*Bell Systems Technical Journal*, 49, no. 5, May/Jun. 1970, pp. 683–698.

Table B1

Resistors

a) Fixed Resistor Selection Guide

Section	Type	Styles available in standard
101 (MIL-R-11)	Composition (insulated)	
102 (MIL-R-10509)	Film (high stability)	RN75
103 (MIL-R-11804)	Film (power type)	RD60 RD65 RD70
104 (MIL-R-93)	Wire-wound (accurate)	
106 (MIL-R-26)	Wire-wound (power type)	RW29 RW31 RW33 RW35 RW37 RW38 RW47 RW56
107 (MIL-R-22684)	Film (insulated)	
108 (MIL-R-18546)	Wire-wound (power type, chassis mount)	RE77 RE80
301 (MIL-R-39008)	Composition (insulated), established reliability	RCR05 RCR07 RCR20 RCR32 RCR42
302 (MIL-R-55182)	Film, established reliability	RNR50 RNR55 RNR 60 RNR 65 RNR 70
303 (MIL-R-39005)	Wire-wound (accurate), established reliability	RBR52 RBR53 RBR54 RBR55 RBR56 RBR57 RBR71 RBR72
304 (MIL-R-39007)	Wire-wound (power type), established reliability	RWR74 RWR78 RWR80 RWR81 RWR84 RWR89
305 (MIL-R-39017	Film (insulated) established reliability	RLR05 RLR07 RLR20 RLR32 RLR42
306 (MIL-R-39003)	Wire-wound (power type, chassis mount), established reliability	RER40 RER45 RER50 RER55 RER60 RER65 RER70 RER75

B3.3 Resistors

These resistors meet the nonaging criteria when they are applied within their wattage ratings as follows:

Type	Applied Stress in Percent of Rated Watts
Carbon	50%
Film	50%
Wire bound	60%

NOTE — The above stress values were obtained from MIL-Std-199B-1974, Selection and Use of Resistors.

Various grades of resistors, from Mil-Spec to commercial grade, are available for use in Class 1E charger/inverter applications. The non-aging criteria apply to the resistors in Table B1 as long as they are used within their wattage ratings as stated above and manufactured with techniques used to manufacture the equivalent Mil-Spec resistors.

NOTE — Mil-Spec resistors are not required by this document.

Table B1 —Resistors

(b) Variable Resistor Selection Guide

Section	Type	Styles available in standard
201 (MIL-R-94)	Composition (insulated)	RV4 RV6
202 (MIL-R-19)	Wire-wound (low operating temperature)	RA20 RA30
203 (MIL-R-22)	Wire-wound (power Type)	RP05 RP06 RP10 RP15 RP20 RP25 RP30
204 (MIL-R-12934)	Wire-wound, precision	RR0900 RR1000 RR1100 RR1300 RR1400 RR2000 RR2100 RR3000
205 (MIL-R-39002)	Wire-wound, semi precision	RK09
206 (MIL-R-27208	Wire-wound (lead screw actuated)	RT26
207 (MIL-R-22097)	Nonwire-wound (lead screw actuated)	RJ12 RJ22 RJ24 RJ26

		RJ50
208 (MIL-R-23285)	Nonwire-wound	RVC5 RVC6
401 (MIL-R-39015)	Wire-wound (lead screw actuated), established reliability	RTR12 RTR22 RTR24
402 (MIL-R-39035)	Nonwire-wound (lead-screw actuated), established reliability	RJR12 RJR24

“Flameproof Resistors—Select Them Carefully or You May Get Burned,” *Electronic Products Magazine,* Aug. 15, 1983.

The Truth About Resistors. Ohmite Manufacturing Company, 1977.

B3.4 Tantalum Dry Electrolytic Capacitors

EPRI NP-3326, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components—Phase 1, Dec. 1983.*

EPRI NP-5024, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components—Phase 2, Jan. 1987*

Didinger, G. H., Jr. “On the Reliability of Solid Tantalum Capacitors, and Reliability Measurement and Prediction for Solid Tantalum Capacitors.” Kemet Company, Union Carbide Corporation, 1961.*

Holladay, Dr. A. M. “Guidelines of the Selection and Application of Tantalum Electrolytic Capacitors in Highly Reliable Equipment.” NASA TMX-64755 Rev A, Jan. 31, 1978.*

Maguire, D. E. “An Application of the Weibull Distribution to the Determination of the Reliability of Solid Tantalum Capacitors.” Kemet Company, Union Carbide Corporation, 1961.

Mandakis, B. J. “The Solid Tantalum Capacitor—A ‘Solid’ Contributor to Reliability.” Electronic Communications Inc., St. Petersburg, Florida, *Proceedings of the 11th Annual Reliability Physics Conference,* 1973.

Stout, H. L. “Extended Life Test of Solid Electrolyte Tantalum Capacitors.” Army Electronics Command, Fort Monmouth, NJ (037620).*

B3.5 Capacitors (Ceramic, Paper, Plastic Film, Mica, Glass)

With the exception of oil-filled type paper or plastic film capacitors, the non-aging criteria applies, provided the capacitors are manufactured using the same techniques used in manufacturing the equivalent Mil-Spec components listed in Table B2. For additional information see Mil-Std-198D-1976, Selection and Use of Capacitors.

NOTE — This standard does not require the use of Mil-Spec components.

EPRI NP-3326, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components—Phase 1, Dec. 1983.*

EPRI NP-5024. Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components—Phase 2, Jan. 1987.*

B3.6 Integrated Microelectronic Devices and Hybrid Microcircuits

EPRI NP-3326. Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components—Phase 1, Dec. 1983.*

EPRI NP-5024. Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components—Phase 2, Jan. 1987.* MIL-HDBK217E-1986, Reliability Prediction of Electronic Equipment.

NOTE — This document contains an extensive bibliography.

Aaron, D. and Adam, M. “MOS Reliability Prediction Model.” 9th Reliability and Maintainability Symposium, Jul. 1970.

Fuchs, J. and Lauffenburger, H. A. “System for Effective Transferal of Microelectronic Reliability Experience.” 8th Reliability Maintainability Symposium, Jul. 1969.

Lehtonen, D. E. “Microcircuit Reliability Assessment through Accelerated Testing.” *Electronic Packaging and Production*, Jul. 1977.

Schmid, E. R. “How to Eliminate Premature Semiconductor Failures.” *Machine Design*, August 25, 1977.*

Wahl, A. J. “Ten years of Power Aging of the Same Group of Submarine Cable Devices.” *Bell System Technical Journal*, vol. 56, no. 6, Jul./Aug. 1977.*

Weissflug, V. A. and Sisual, E. V. Cyclic and Low Temperature Effects on Microcircuits.” McDonnell Douglas Astronautics Company, East. Final Technical Report prepared for the George C. Marshall Space Flight Center, Aug. 1975-Aug. 1977.*

Table B2 —Capacitors

Dielectric	Applicable Specification
Glass	
Fixed	MIL-C-23269 (ER)
Variable 1	MIL-C-14409
Mica	MIL-C-10950
Button style	MIL-C-5
General purpose	MIL-C-39001 (ER)
Electrolytic	
Tantalum (solid)	MIL-C-39003 (ER)
Tantalum (solid) chip	MIL-C-55365 (ER)
Paper	
Wax-impregnated	MIL-C-12889
Metallized	MIL-C-39022 (ER)
Paper-Plastic	
Polycarbonate	MIL-C-19978 (ER)
Paper & polyethylene terephthalate	MIL-C-19978 (ER)
Plastic or metallized plastic	MIL-C-55514 (ER)
Polyethylene terephthalate	MIL-C-19978 (ER)
Ceramic	MIL-C-11015
Fixed, general purpose	MIL-C-39014 (ER)
Temp compensating	MIL-C-20 (ER)
Variable	MIL-C-81
Fixed, chip	MIL-C-55681 (ER)
Gas or vacuum	
Fixed	MIL-C-23183
Variable	MIL-C-23183

Annex C

Nonelectronic Components for Which Aging is not a Failure Mechanism

(Informative)

C1. General

Aging is not a failure mechanism for certain nonelectronic components used as structural, nonwire insulating elements, and connections (in typical Class 1E charger/inverter applications) that are processed using approved methods. The quality assurance procedures required for nuclear safety applications by ASME NQA-1-1986, Quality Assurance Requirements for Nuclear Facilities (see C2.1), and 10-CFR-50, Regulations Relating to Commerce and Foreign Trade, Appendix B (see C2.1), provide for stringent controls of such processes as welding, soldering and crimping, and assembly and finishing. One of the purposes of these controls is to assure that no degradation of structural integrity occurs to mechanical parts, fasteners, and the like. In addition, IEEE Std 344-1987 [12] specifically requires that equipment that is to be qualified be subjected to requirements that simulate the effects of structural-related aging on the equipment. The following components do not have a significant age-related failure mechanism when used in Class 1E static battery chargers and inverters:

1) Aluminum
2) Brass
3) Ceramic
4) Copper
5) Steel

C2. Bibliography — Nonmetallic, Nonelectronic Components

An extensive bibliography has been assembled to justify that certain nonmetallic components, as used in typical Class 1E charger/inverter applications, do not have age-related failure mechanisms within a service life of 40 years.

NOTE — References that contain specific conclusions that support the non-aging concept are followed by an asterisk.

C2.1 Epoxy Fiberglass Grade G-10 and G-11 or Equivalent (not Exposed to Bright Light for Prolonged Periods)

ASME NQA-1-1986, Quality Assurance Requirements for Nuclear Facilities.[9]

EPRI NP-3326, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components — Phase 1, Dec. 1983.*

EPRI NP-5024, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components — Phase 2, Jan. 1987.*

EPRI NP-2129, Report of Radiation Effects on Organic Materials in Nuclear Plants.

Darmory, F. P. “Polyimide Lamination Resin for Multilayer Printed Wiring Boards.” *Insulation/Circuits*, vol. 21, no.10, 1974.*

DeForest, W. S., Connelly, H. V., and Marro, S. “The Effect of Heat Aging and Related Phenomenon on the Black-Oxide-Epoxy Band.” 1977 National Electronic Packaging Conference Proceedings WEST, Mar. 1977, pp. 1–7.
Eisler, P. *The Technology of Printed Circuits.* London, England: Heywood and Company, 1959.

Establish Improved Manufacturing Processes for Polyimide Printed Circuit Boards. USAF Contract no. F33615-76-5045, Interim Report No. 1–5.

---

[9] ASME publications are available from the Order Department, American Society of Mechanical Engineers, 22 Law Drive, Box 2300, Fairfield, NJ 07007-2300, USA.

Hayes, L.E., and Mayfield, R. E. “A Critical Look at Polyimide/Glass Multilayer Boards. ”1975 National Electronic Packaging Conference Proceedings, 1975.

Mayfield, R. E. “A Critical Look at Polyimide Glass Multilayer Boards.” IPC Publication TP-80, Apr. 1976.

Reliability Study of Polyimide/Glass Multilayer Boards. RADC-TR-73-400, Final Technical Report, Martin Marietta Aerospace, Jan. 1974.*

Rhodia Technical Information Bulletin on Kerimid 500, April 1973.

Schiavo, J. S. and Mearns, R. M. “Multilayer Board Reliability.” *Electronic Packaging and Production,* vol. 16, no. 1, Jan. 1976.*

Schussler, P. “Preventing Delamination of Circuit Boards and Flexible Circuits.” *Insulation/Circuits,* vol. 20, no. 7, Jul. 1973.

10-CFR-Title 15, Regulations Relating to Foreign Trade, Appendix B, 869-011-000-48-7.[10]

C2.2 Glass-Filled Diallyl Phthalate

ASME NQA-1-1986, Quality Assurance Requirements for Nuclear Facilities.

EPRI NP-2129, Report of Radiation Effects on Organic Materials in Nuclear Plants.

EPRI NP-3326, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components — Phase 1, Dec. 1983.*

EPRI NP-5024, Correlation Between Aging and Seismic Qualification for Nuclear Plant Electrical Components — Phase 2, Jan. 1987.*

RADC TR-71-299, Reliability of Ceramic Multilayer Boards (Final technical report, May 1070–Jun. 1971). AD-737 373.[11]

RADC-TR-73-171, Reliability Study Circular Electrical Connectors (Final technical report, Jan. 1972–Jan. 1973). AD-765 609/3.

RADC-TR-73-400, Reliability Study of Polyimide/Glass Multilayer Boards (Final technical report, Mar. 1972–Jun. 1973). AD-777 194/2.

RADC-TR-74-88, Infrared Testing of Multilayer Boards (Final report Sep. 1973–Jan. 1974). AD-780 550/0.

RADC-TR-75-22, Nonelectronic Reliability Notebook (Final report). AD-A005 657/2.

Proceedings of the Tenth Electrical/Electronics Insulation Conference. IEEE 1974, pub no 71C 38-EI.*

10-CFR-Title 15, Regulations Relating to Foreign Trade, Appendix B, 869-011-000-48-7.

---

[10] Federal regulations are available from the Government Printing Office, 732 N. Capitol Street NE, Washington, DC 20401, USA.

[11] RADC documents are available from Customer Services Staff, NTIS—US Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161, USA.

Annex D

Discussion of Failure Mechanisms in Electromechanical Devices

(Informative)

The predominant cause of failure of electromechanical devices used in chargers and inverters is cycle-induced fatigue. This applies to relays, switches (including contactors), and circuit breakers when applied properly in the design in terms of electrical stress. This statement applies to electromechanical devices using approved materials of the types described in Appendix C, or other qualified components. Thus, an analysis, in accordance with 5.1.2, of the materials employed in the devices is required.

Some concern has been voiced about relays and other devices that, after being kept in the same state (energized or de-energized) for a period of years, are called upon to act, only to be found frozen into position. This may not apply to chargers and inverters for the following reasons:

1) Routine plant maintenance of batteries to which the chargers and inverters are connected may require that the equipment be turned on and off, as well as disconnected, one or two times a year. This action would cycle all the devices in questions.

2) Maintenance replacements of limited-life items may occur every few years, again cycling these devices.

These electromechanical devices have typically been endurance tested by the device manufacturer for tens and hundreds of thousands of operations. As applied in battery chargers and inverters, these devices will typically be subjected to only a few hundred operations over their expected qualified life. The actual operating duty is therefore only a small fraction of the tested life of the device, and thus provides a very high design margin.

As a result of the above, cycling these electromechanical devices to the total number of anticipated cycles during the qualified life period under equivalent stress (load) conditions, along with the final temperature-humidity seismic testing of the equipment itself, will provide a reasonable simulation of expected condition at the end of the qualified life period.

Annex E

Cycling of Connectors

(Informative)

In Class 1E battery chargers and static inverters, wire and cable harnesses, and their associated connectors and terminal blocks, are fixed objects after they have passed final inspection and acceptance by the customer. Connector disconnect and reconnect may occur on a very low duty cycle basis. This can be demonstrated by performing mean time between failure (MTBF) calculations on the associated circuit board assemblies to determine their replacement interval. There is no planned maintenance requirement for operation of the connectors or terminal blocks. Thus, cycling of these devices, as employed in this equipment, is not an age-related failure mechanism. For more information, refer to IEEE Std 572-1985, IEEE Standard Qualification of Class 1E Connection Assemblies for Nuclear Power Generating Stations.[12]

[12] See Footnote 5.