JOINT CANADA-UNITED STATES
NATIONAL STANDARD

# ANSI/CAN/UL 1973:2022

## STANDARD FOR SAFETY

Batteries for Use in Stationary and Motive Auxiliary Power Applications



ANSI/UL 1973-2022

## SCC FOREWORD

### National Standard of Canada

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UL Standard for Safety for Batteries for Use in Stationary and Motive Auxiliary Power Applications, ANSI/CAN/UL 1973

Third Edition, Dated February 25, 2022

***Summary of Topics***

***The Third Edition of UL 1973 has been issued to reflect the latest ANSI and SCC approval dates, and to incorporate the proposals dated May 21, 2021 and October 29, 2021.***

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated May 21, 2021 and October 29, 2021.

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ANSI/UL 1973-2022

FEBRUARY 25, 2022



# ANSI/CAN/UL 1973:2022

## Standard for Batteries for Use in Stationary and Motive Auxiliary Power Applications

The title of the First Edition of UL 1973 was the Standard for Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications.

The title of the Second Edition of UL 1973 was the Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications.

First Edition – February, 2013
Second Edition – February, 2018

**Third Edition**

**February 25, 2022**

This ANSI/CAN/UL Safety Standard consists of the Third Edition.

The most recent designation of ANSI/UL 1973 as an American National Standard (ANSI) occurred on February 25, 2022. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, Preface or SCC Foreword.

This standard has been designated as a National Standard of Canada (NSC) on February 25, 2022.

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# Preface

This is the Third Edition of the ANSI/CAN/UL 1973, Standard for Batteries for Use in Stationary and Motive Auxiliary Power Applications.

UL is accredited by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC) as a Standards Development Organization (SDO).

This Standard has been developed in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization.

This ANSI/CAN/UL 1973 Standard is under continuous maintenance, whereby each revision is approved in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization. In the event that no revisions are issued for a period of four years from the date of publication, action to revise, reaffirm, or withdraw the standard shall be initiated.

In Canada, there are two official languages, English and French. All safety warnings must be in French and English. Attention is drawn to the possibility that some Canadian authorities may require additional markings and/or installation instructions to be in both official languages.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at http://csds.ul.com.

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This Edition of the Standard has been formally approved by the UL Standards Technical Panel (STP) on Batteries Used in Stationary and in Light Electric Rail Applications, STP 1973.

This list represents the STP 1973 membership when the final text in this standard was balloted. Since that time, changes in the membership may have occurred.

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This Standard is intended to be used for conformity assessment.

The intended primary application of this standard is stated in its scope. It is important to note that it remains the responsibility of the user of the standard to judge its suitability for this particular application.

CETTE NORME NATIONALE DU CANADA EST DISPONIBLE EN VERSIONS FRANÇAISE ET ANGLAISE.

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## INTRODUCTION

### 1 Scope

1.1 These requirements cover battery systems as defined by this standard for use as energy storage for stationary applications such as for PV, wind turbine storage or for UPS, etc. applications. These systems shall be installed in accordance with NFPA 70, C22.1, or other applicable installation codes.

1.2 These requirements also cover battery systems as defined by this standard for use in light electric rail (LER) applications and stationary rail applications such as rail substations. These systems are intended for installation within either the rail car or within a sheltered stationary location such as a rail substation. These battery systems may utilize regenerative braking from the trains as a source of energy for recharging and are intended for direct or indirect connection to the rail power lines. These battery systems are intended for balancing loads during peak hours, serving as an energy storage device during regenerative breaking of the trains, and as a source of emergency power to move trains to the nearest station during power outages.

1.3 These requirements are also applicable to batteries for use in vehicle auxiliary power (VAP) systems that are utilized in recreational vehicles and other vehicles to provide power for various applications such as lighting and appliances. These batteries are not used for traction power in the vehicles, since batteries for traction power are to be evaluated to UL/ULC 2580 and UL/ULC 2271 as applicable to the intended motive application.

1.4 Annex B of this standard includes requirements specific to sodium-beta type technologies. Annex C of this standard includes requirements specific to flowing electrolyte technologies. Annex H of this standard includes requirements specific to vented and valve regulated lead acid and nickel cadmium batteries. Annex I of this standard includes requirements specific to mechanically recharged metal-air batteries.

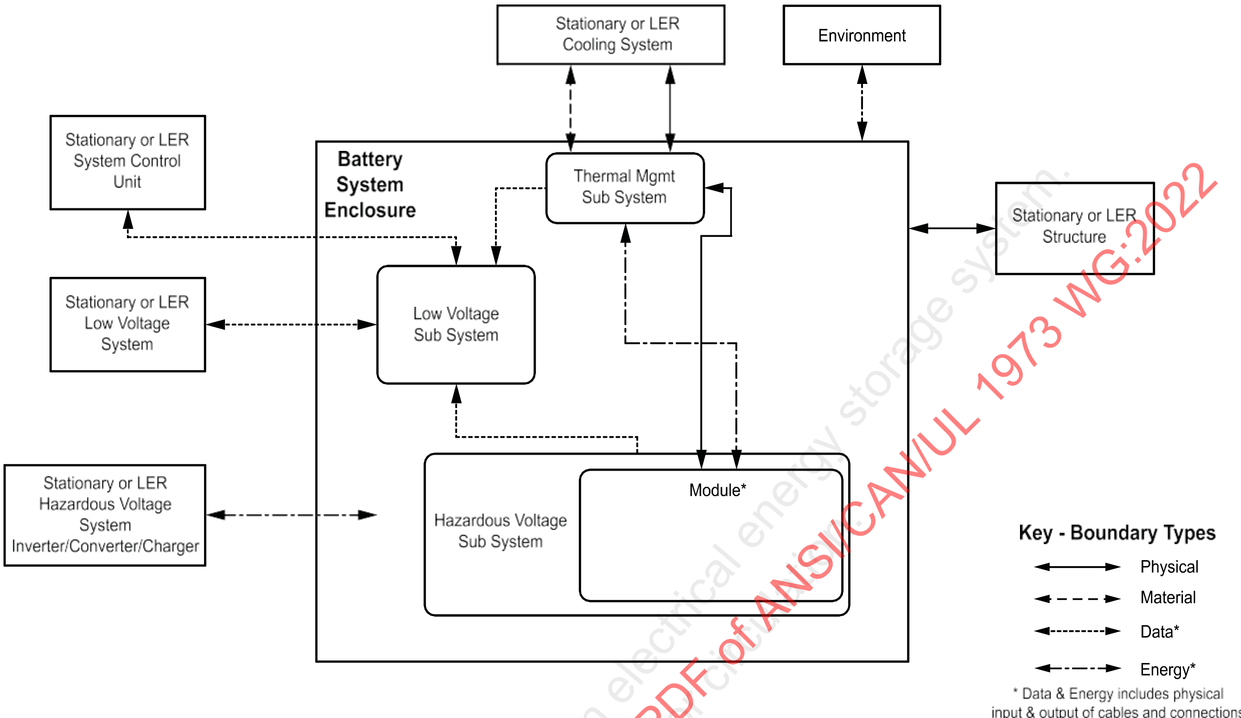
1.5 This standard evaluates the battery system's ability to safely withstand simulated abuse conditions. This standard evaluates the system based upon the manufacturer's specified charge and discharge parameters.

1.6 This standard does not evaluate the performance (i.e. capacity measurements under various discharge conditions) or reliability (i.e. capacity measurements under various environmental conditions) of these devices.

1.7 Figure 1.1 is a boundary diagram example for a battery system for this application. Figure 1.2 is a boundary diagram example for a module for this application.

## Figure 1.1

## Components of a battery system

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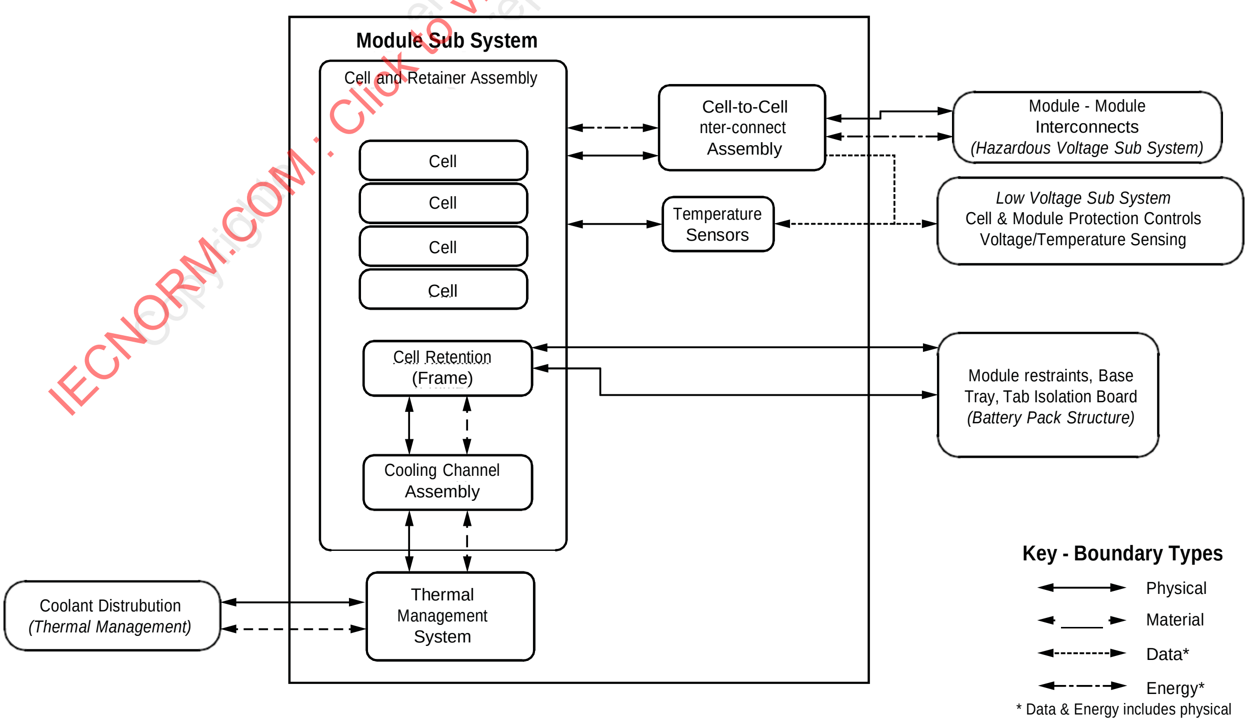
## Figure 1.2

## Module – boundary diagram

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## 2 Components

2.1 A component of a product covered by this standard shall comply with the requirements for that component. See Annex A for a list of standards covering components generally used in the products covered by this standard. A component shall comply with the CSA, UL, and/or ULC standards as appropriate for the country where the product is to be used.

## 3 Units of Measurement

3.1 Values and their respective units of measurement that are stated without parentheses constitute the requirement of the standard and those in parentheses constitute explanatory or approximate information.

## 4 Undated References

4.1 Any undated reference appearing in the requirements of this standard shall be interpreted as referring to the latest edition of the reference, including all revisions and amendments.

## 5 Normative References

5.1 The following standards are referenced in this standard, and portions of these referenced standards may be essential for compliance. Battery systems covered by this standard shall comply with the referenced installation codes and standards as appropriate for the country where the battery system is to be used. When the battery system is intended for use in more than one country, the battery system shall comply with the installation codes and standards for all countries where it is intended to be used.

**American Society of Mechanical Engineers (ASME) Codes**

ASME B31.3, *Process Piping Code*

ASTM B117, *Standard Practice for Operating Salt Spray (Fog) Apparatus*

ASME BPVC, *Boiler and Pressure Vessel Code*

**American Society for Testing and Materials (ASTM) Standards**

ASTM D543, *Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents*

ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

ASTM D4490, *Standard Practice for Measuring the Concentration of Toxic Gases or Vapors Using Detector Tubes*

ASTM D4599, *Standard Practice for Measuring the Concentration of Toxic Gases or Vapors Using Length-of-Stain Dosimeters*

**CSA Group Standards**

CSA C22.1, *Canadian Electrical Code, Part I Safety Standard for Electrical Installations*

CAN/CSA-C22.2 No. 0, *General Requirements – Canadian Electrical Code, Part II*

CSA C22.2 No. 0.15, *Adhesive Labels*

CAN/CSA-C22.2 No. 0.17, *Evaluation of Properties of Polymeric Materials*

CAN/CSA-C22.2 No. 0.2, *Insulation Coordination*

CSA C22.2 No. 0.8,*Safety Functions Incorporating Electronic Technology*

CSA C22.2 No. 94.2, *Enclosures for Electrical Equipment, Environmental Considerations*

CAN/CSA C22.2 No. 107.2, *Battery Chargers*

CSA C22.2 No. 113, *Fans and Ventilators*

CSA C22.2 No. 60335-2-29, *Household and Similar Electrical Appliances – Safety – Part 2-29: Particular Requirements for Battery Chargers*

CAN/CSA-E60730-1, *Automatic Electrical Controls for Household and Similar Use – Part 1: General Requirements*

CAN/CSA-C22.2 No. 62368-1, *Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements*

**Institute of Electrical and Electronics Engineers (IEEE) Standards**

IEEE 693, *Recommended Practice for Seismic Design of Substations*

IEEE 1625, *Rechargeable Batteries for Multi-Cell Mobile Computing Devices*

IEEE 1635/ASHRAE Guideline 21, *Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications*

IEEE 1725, *Rechargeable Batteries for Cellular Telephones*

**International Code Council (ICC)**

ICC IBC, *International Building Code*

**International Electrotechnical Commission (IEC) Standards**

IEC 60068-2-52, *Environmental Testing Part 2: Tests – Tests Kb, Salt Mist, Cyclic (Sodium Chloride Solution)*

IEC 60068-2-64, *Environmental Testing – Part 2-64: Tests – Test Fh: Vibration, Broadband Random and Guidance*

IEC 60364-6, *Low-Voltage Electrical Installations – Part 6: Verification*

IEC 60417 Database, *Graphical Symbols for Use on Equipment*

IEC 60529, *Degrees of Protection Provided by Enclosures (IP Code)*

IEC 60664-1, *Insulation Coordination for Equipment Within Low-voltage Supply Systems – Part 1: Principles, Requirements and Tests*

IEC 60812, *Analysis Techniques for System Reliability – Procedures for Failure Mode and Effects Analysis (FMEA)*

IEC 61000-4-2, *Electromagnetic Compatibility (EMC) – Part 4-2: Testing and Measurement Techniques – Electrostatic Discharge Immunity Test*

IEC 61000-4-3, *Electromagnetic Compatibility (EMC) – Part 4-3: Testing and Measurement Techniques – Radiated, Radio-Frequency, Electromagnetic Field Immunity Test*

IEC 61000-4-4, *Electromagnetic Compatibility (EMC) – Part 4-4: Testing and Measurement Techniques – Electrical Fast Transient/Burst Immunity Test*

IEC 61000-4-5, *Electromagnetic Compatibility (EMC) – Part 4-5: Testing and Measurement Techniques – Surge Immunity Test*

IEC 61000-4-6, *Electromagnetic Compatibility (EMC) – Part 4-6: Testing and Measurement Techniques – Immunity to Conducted Disturbances, Induced by Radio-Frequency Fields*

IEC 61000-4-8, *Electromagnetic Compatibility (EMC) – Part 4-8: Testing and Measurement Techniques – Power Frequency Magnetic Field Immunity Test*

IEC 61025, *Fault Tree Analysis (FTA)*

IEC 61373, *Railway Applications – Rolling Stock Equipment – Shock and Vibration Tests*

IEC 61508 (all parts), *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems*

IEC TR 62660-4, *Secondary Lithium-Ion Cells for the Propulsion of Electric Road Vehicles – Part 4: Candidate Alternative Test Methods for the Internal Short Circuit Test of IEC 62660-3*

**International Standards Organization (ISO) Standards**

ISO 7000, *Graphical Symbols for Use on Equipment – Registered Symbols*

ISO 9227, *Corrosion Tests in Artificial Atmospheres – Salt Spray Tests*

ISO 13355, *Packaging – Complete, Filled Transport Packages and Unit Loads – Vertical Random Vibration Test*

ISO 13849 (all parts), *Safety of Machinery – Safety-Related Parts of Control Systems*

ISO 26262 (all parts), *Road Vehicles – Functional Safety*

**National Electrical Manufacturers Association (NEMA)**

NEMA 250, *Enclosures for Electrical Equipment (1000 Volts Maximum)*

**National Fire Protection Association (NFPA) Codes and Standards**

NFPA 2, *Hydrogen Technologies Code*

NFPA 68, *Explosion Protection by Deflagration Venting*

NFPA 69, *Explosion Prevention Systems*

NFPA 70, *National Electrical Code*

**National Institute for Occupational Safety and Health (NIOSH)**

*Manual of Analytical Methods*

**Occupational Safety and Health Standards (OSHA)**

*Evaluation Guidelines for Air Sampling Methods Utilizing Spectroscopic Analysis*

**Society of Automotive Engineers (SAE) Standards**

SAE J2464, *Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing*

**Telcordia**

GR-63-CORE, *Network Equipment – Building System (NEBS) Requirements: Physical Protection*

**UL Standards**

UL 50E, *Enclosures for Electrical Equipment, Environmental Considerations*

UL 94, *Tests for Flammability of Plastic Materials for Parts in Devices and Appliances*

UL 157, *Gaskets and Seals*

UL 263, *Fire Tests of Building Construction and Materials*

UL 507, *Electric Fans*

UL 546, *Conductor Termination Compounds*

UL 583, *Electric-Battery-Powered Industrial Trucks*

UL 746A, *Polymeric Materials – Short Term Property Evaluations*

UL 746B, *Polymeric Materials – Long Term Property Evaluations*

UL 746C, *Polymeric Materials – Use in Electrical Equipment Evaluations*

UL 746E, *Polymeric Materials – Industrial Laminates, Filament Wound Tubing, Vulcanized Fibre, and Materials Used in Printed Wiring Boards*

UL 810A, *Electrochemical Capacitors*

UL 840, *Insulation Coordination Including Clearances and Creepage Distances For Electrical Equipment*

UL 969, *Marking and Labeling Systems*

UL 991, *Tests for Safety-Related Controls Employing Solid-State Devices*

UL 1012, *Power Units Other Than Class 2*

UL 1310, *Class 2 Power Units*

UL 1562, *Transformers, Distribution, Dry-Type – Over 600 Volts*

UL 1642, *Lithium Batteries*

UL 1741, *Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources*

UL 1974, *Evaluation for Repurposing Batteries*

UL 1989, *Standby Batteries*

UL 1998, *Software in Programmable Components*

UL 2054, *Household and Commercial Batteries*

UL/ULC 2271, *Batteries for Use in Light Electric Vehicle (LEV) Applications*

UL 2416, *Audio/Video, Information and Communication Technology Equipment Cabinet, Enclosure and Rack Systems*

UL 2436, *Spill Containment for Stationary Lead Acid Battery Systems*

UL/ULC 2580, *Batteries for Use in Electric Vehicles*

UL 5500, *Remote Software Updates*

UL 9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*

UL 60335-2-29, *Household and Similar Electrical Appliances – Safety – Part 2-29: Particular Requirements for Battery Chargers*

UL 60730-1, *Automatic Electrical Controls for Household and Similar Use, Part 1: General Requirements*

UL 62368-1, *Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements*

**ULC Standards**

ULC/ORD-C583, *Guide for the Investigation of Electric Battery Powered Industrial Trucks*

**US Department of Defense (DOD) Standards**

MIL STD 1629A, *Procedures for Performing a Failure Mode, Effects, and Criticality Analysis*

## 6 Glossary

6.1 BATTERY – A general term for either a single cell or a group of cells connected together either in a series and/or parallel configuration.

6.2 BATTERY MANAGEMENT SYSTEM (BMS) – A battery control circuit with active and programmable active protection devices that monitors and maintains the cells within their safe operating region; and which prevents overcharge, overcurrent, overtemperature, under-temperature and overdischarge conditions of the cells.

6.3 BATTERY PACK – Batteries that are ready for use, contained in a protective enclosure, which may or may not contain protective devices, cooling systems and monitoring circuitry. Although batteries may be the dominant energy storage device in the pack, the battery pack may include electrochemical capacitors as a type of hybrid pack.

6.4 BATTERY SYSTEM – Consists of a pack (i.e. battery, capacitor or hybrid pack) and external controls and circuitry related to the pack such as cooling systems, disconnects or protection devices external to the pack.

6.5 CAPACITOR PACK – Electrochemical capacitors that are ready for use in a battery system, contained in a protective enclosure, with or without protective devices, cooling systems, and monitoring circuitry. Although electrochemical capacitors may be the dominant energy storage device in the pack, the capacitor pack may include batteries as a type of hybrid pack.

6.6 CAPACITY, RATED ($C_n$) – The total number of ampere-hours that can be withdrawn from a fully charged battery at a specific discharge rate to a specific end-of-discharge voltage (EODV) at a specified temperature as declared by the manufacturer.

6.7 CASCADING – The runaway failure or thermal propagation of a battery system or battery module when:

a) One battery cell is triggered into catastrophic failure and this cell causes the failure of neighboring cells; and/or

b) Continued thermal propagation of catastrophic cell failures until part of or the entire system is on fire or causing excessive hazardous gas generation or leakage of hazardous liquids.

6.8 CASING – The container that directly encloses and confines the contents of a cell, monobloc battery or electrochemical capacitor.

6.9 CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

6.10 CELL, CYLINDRICAL – A cell format with a rigid case that has straight parallel sides and a round cross section.

6.11 CELL, POUCH – A cell format with a flexible laminate case that is typically, but not limited to a prismatic shape, and that can have its tabs on the same side or on opposite sides of each other.

6.12 CELL, PRISMATIC – A cell format with a rigid case that has a rectangular shape.

6.13 CELL, SECONDARY – A cell that is intended to be discharged and recharged many times in accordance with the manufacturer's recommendations.

6.14 CELL BLOCK – One or more cells connected in parallel.

6.15 CHARGING – The application of electric current to battery or capacitor terminals, which results in a Faradic reaction that takes place within the battery that leads to stored electro-chemical energy or in the case of the capacitor, due to electrical charge being stored without a chemical reaction taking place.

6.16 CHARGING, CONSTANT CURRENT (CC) – Charging mode where current is held constant while charging voltage is allowed to vary.

6.17 CHARGING, CONSTANT VOLTAGE (CV) – Charging mode where voltage is held constant while charging current is allowed to vary.

6.18 COMBUSTIBLE VAPOR CONCENTRATION – A concentration in air greater than 25 % of the lower flammable limit (LFL) of the flammable vapor being measured or a concentration that can be ignited in accordance with 7.1.

6.19 CRITICAL SAFETY – Any devices or circuits provided to protect against hazardous conditions where the failure of the device results in a hazardous condition as defined in UL 991.

6.20 DUT – Device under test.

6.21 ELECTROCHEMICAL CAPACITOR – An electric energy storage device where electrical charge is typically stored as a result of non-Faradaic reactions at the electrodes. (A subset of electrochemical capacitors referred to as an "asymmetric" type have non-Faradaic reactions at one electrode and Faradaic reactions at the other electrode.) A highly-porous surface of the electrodes increases the surface area for holding charge resulting in much larger capacitance and energy density. Electrochemical capacitors differ from common electrolytic capacitors in that they employ a liquid rather than a solid dielectric with charge occurring at the liquid-solid interface of the electrodes when a potential is applied. Some other common names for an electrochemical capacitor are "double layer capacitor", "ultracapacitor", "electrochemical double layer capacitor", "super capacitor", and "EDLC".

6.22 ENCLOSURE – The protective outer cover of the pack or battery system that provides mechanical protection to the pack/system's contents.

NOTE: A flow battery stack is not considered an enclosure if protected by the outer enclosure of the system.

6.23 END-OF-DISCHARGE VOLTAGE (EODV) (Cell) – The voltage, under load, of the cell at the end of discharge. The EODV may be specified by the manufacturer, as in the case of a voltage-terminated discharge typical for lithium ion chemistries.

6.24 EXPLOSION – A violent release of energy that produces projectiles or a pressure wave from the DUT and results in DUT contents being forcibly expelled through a rupture in the enclosure or casing.

6.25 FIRE – The sustained combustion of the DUT's contents as evidenced by flame, heat, and charring or other damage of materials.

6.26 FLOWING ELECTROLYTE BATTERY – A rechargeable battery that stores its active materials, in the form of liquid aqueous electrolytes, external to the battery. The electrolytes, which serve as energy carriers, are pumped through two half cells separated by an ion-permeable separator, which provides separation of the two electrolytes while still allowing for the passage of ions during charging and discharging. Charging and discharging results in a chemical reduction reaction in one electrolyte and an oxidation reaction in the other electrolyte. Ions selectively pass through the separator membrane to complete the redox reaction. When in use the electrolytes are continuously pumped in a circuit between reactor and storage tanks. Three commercially available flowing electrolyte batteries technologies, two of which are zinc-based and a third, the vanadium redox types, are described below:

a) ZINC AIR – A flowing electrolyte battery technology that has one active aqueous electrolyte containing metal particles. During charging, zinc particles are generated from a zincate solution in a chemical reaction (oxygen is off gassed from the reaction), and then transported to a storage tank in a KOH solution as a charged electrolyte. During discharge the electrolyte is pumped through the reactor interface (flow battery stack) where the zinc particles combine again with oxygen from the surrounding air to form zincate.

b) ZINC BROMINE – A flowing electrolyte battery technology that has zinc at the negative electrode and bromide at the positive electrode with an aqueous solution containing zinc bromide and other compounds contained in two separate reservoirs. During charging, energy is stored as zinc metal within the cell and polybromide in the cathode reservoir. During discharge, the zinc is oxidized to zinc oxide and the bromine is reduced to bromide.

c) VANADIUM REDOX – A flowing electrolyte battery technology that contains vanadium salts in various stages of oxidation in a sulfuric acid, or in a mixture of sulfuric and hydrochloric acid electrolyte. Charging and discharging the battery changes the oxidation state of the vanadium in the electrolyte solutions.

6.27 FULLY CHARGED – A battery system, pack, module or cell which has been charged to its full state of charge (SOC) as specified by the manufacturer.

6.28 FULLY DISCHARGED – A battery system, pack, module or cell, which has been discharged to its end-of-discharge voltage (EODV) as specified by the manufacturer.

6.29 HAZARDOUS VOLTAGE – A sinusoidal voltage exceeding 42.4 Vpeak or 60 Vdc is considered hazardous.

6.30 INSULATION LEVELS – The following are levels of electrical insulation:

a) BASIC INSULATION – Insulation to provide basic protection against electric shock.

b) DOUBLE INSULATION – Insulation comprising both basic insulation and supplementary insulation.

c) FUNCTIONAL INSULATION – Insulation that is necessary only for the correct functioning of the equipment. Functional insulation by definition does not protect against electric shock. It may, however, reduce the likelihood of ignition and fire.

d) REINFORCED INSULATION – Single insulation system that provides a degree of protection against electric shock equivalent to double insulation under the conditions specified in this standard. The term "insulation system" does not imply that the insulation has to be in one homogeneous piece. It may comprise several layers that cannot be tested as basic insulation and supplementary insulation.

e) SUPPLEMENTARY INSULATION – Independent insulation applied in addition to basic insulation in order to reduce the risk of electric shock in the event of a failure of the basic insulation.

6.31 LEAKAGE – A condition where liquid escapes through an opening in a designed vent or through a rupture or crack or other unintended opening and is visible external to the device under test.

6.32 LIGHT ELECTRIC RAIL (LER) – A term used to specify a commuter train that obtains all of its motive energy from electricity.

6.33 LIMITED POWER CIRCUIT – A circuit supplied by a power source that meets SELV limits and whose power and current are further limited in accordance with the Limited Power Source Test of UL 2054. A limited power source is equivalent to a Class 2 circuit in accordance with Article 725 of NFPA 70 or Section 16 of C22.1. A similar concept to limited power is the term "low-voltage limited energy" (LVLE) as defined in Section 16 of UL 583 or ULC/ORD-C583.

6.34 LITHIUM ION CELL – A rechargeable cell where electrical energy is derived from the insertion/extraction reactions of lithium ions between the anode and the cathode. The lithium ion cell has an electrolyte that typically consists of a lithium salt and organic solvent compound in liquid or gel or solid form and has either a hard metal casing or a flexible polymeric pouch casing.

6.35 LITHIUM METAL CELL – A rechargeable battery technology that employs lithium metal as the anode material.

NOTE: These cells may be referred to as solid state batteries if they employ a solid polymeric or ceramic electrolyte.

6.36 MAINS SUPPLY (AC) – An ac power distribution system external to the equipment for supplying power to ac powered equipment. Examples of ac mains supply include public or private utilities and equivalent sources such as motor-driven generators and uninterruptible power supplies.

6.37 MANUFACTURING PRODUCTION LINE TESTING – Testing at the manufacturer's facilities used as a manufacturing check of their production. Depending upon the testing, it either can be a 100 % production test, or can be a periodic check or sampling of production. This testing is sometimes referred to as routine testing.

6.38 MATERIAL, HYGROSCOPIC – A material that has a strong affinity to attract moisture, will absorb moisture onto its molecular structure if exposed to ambient air, and internal moisture cannot be removed with hot air alone. Examples of hygroscopic materials are: nylon, ABS, acrylic, polyurethane, polycarbonate, PET, and PBT.

6.39 MATERIAL, NON-HYGROSCOPIC – A material that does not have an affinity for moisture and any moisture collected is adsorbed on the surface, typical moisture collection is due to condensation, and moisture is easily removed by passing a sufficient stream of warm air over the material. Examples of non-hygroscopic materials are: polyethylene, polypropylene, polystyrene, PVC.

6.40 MAXIMUM WORKING VOLTAGE – The highest voltage to which the insulation or component under consideration is or can be subjected to when the equipment is operated under conditions of normal use.

6.41 METAL-AIR BATTERY – An electrochemical battery that uses an anode made from pure metal and an external cathode of ambient air, typically with an aqueous or aprotic electrolyte. Primary, reserve, electrically rechargeable, and mechanically rechargeable metal-air battery configurations have been explored and developed. The metals that have been considered for use in metal-air batteries are calcium, magnesium, lithium, aluminum, and iron.

6.42 METAL-AIR BATTERY, MECHANICALLY RECHARGEABLE – A metal-air battery designed with a means to remove and replace the discharged anodes or discharge products (such as reacted electrolyte) with new ones for recharging. The battery essentially functions as a primary battery and the air electrodes operate only in a discharge mode. During discharging of a metal-air electrochemical cell, an oxygen reduction reaction occurs in the ambient air cathode while the metal anode is oxidized. The discharged anode or discharge products can be recharged or reclaimed external to the cell. Commercially available mechanically rechargeable metal-air batteries are Zn-Air batteries and Al-Air batteries.

6.43 MODULE – A subassembly consisting of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry. A module is a component of a battery system. See Figure 1.2.

6.44 MONOBLOC (MULTI-CELL) BATTERY – A battery design that contains series connected cells in a common vessel construction, with a vent assembly or valve assembly and shared hardware.

6.45 MOSOC – Maximum operational state of charge. Refer to 6.1.

6.46 NICKEL CELL – A general term for a nickel cadmium or nickel metal hydride rechargeable cell that has a nickel hydroxide positive electrode and either a cadmium metal or metal hydride negative electrode and that has a liquid alkaline (i.e. KOH) electrolyte.

6.47 NORMAL OPERATING REGION – That region of voltage, current, and temperature within which a cell or electrochemical capacitor can safely be charged and discharged repetitively throughout its anticipated life. The manufacturer specifies these values, which are then used in the safety evaluation of the device and may vary as the device ages. The normal operating region will include the following parameters for charging and discharging as specified by the manufacturer:

a) CHARGING TEMPERATURE LIMITS – The upper and lower limits of temperature, specified by the manufacturer for charging of the cell/capacitor.

NOTE: This temperature is measured on the cell casing.

b) DISCHARGE TEMPERATURE LIMITS – The upper and lower limits of temperature, specified by the manufacturer for discharging the cell/capacitor.

NOTE: This temperature is measured on the cell casing.

c) END OF DISCHARGE VOLTAGE – Refer to 6.23.

d) MAXIMUM CHARGING CURRENT – The maximum charging current in the normal operating region, which is specified by the cell/capacitor manufacturer. This value may vary with temperature.

e) MAXIMUM DISCHARGING CURRENT – The maximum discharging current rate, which is specified by the cell/capacitor manufacturer.

f) UPPER LIMIT CHARGING VOLTAGE – The highest charging voltage limit in the normal operating region specified by the cell/capacitor manufacturer. This value may vary with temperature.

6.48 PRIMARY SAFETY PROTECTION – The safety device or circuit that is part of the safety control system intended to prevent a hazard, and which operates before any secondary or supplemental protection operates.

6.49 PROTECTIVE DEVICES, ACTIVE – Devices provided to prevent hazardous conditions that require electrical energy in order to operate. An example of an active control would be a battery management system (BMS) that has monitoring and control functions.

6.50 PROTECTIVE DEVICES, PASSIVE – Devices provided to prevent hazardous conditions that do not require electrical energy in order to detect the condition and operate. Examples of a passive protective devices would be fuses, thermal snap switches and fluid level switches.

6.51 RESTRICTED ACCESS LOCATION – Location where access to the energy storage system is limited to trained service personnel or others trained to understand the restrictions associated with the system such as access to hazardous parts and precautions to be followed around the equipment. Access to restricted access locations shall be secured by a tool such as a lock and key or other means that is controlled by a person(s) responsible for the location.

6.52 ROOM AMBIENT – Considered to be a temperature in the range of 25 ±5 °C (77 ±9 °F).

6.53 RUPTURE – A mechanical failure of the DUT's enclosure/casing from either internal or external causes, that results in spillage and/or exposure of internal contents of the DUT, but does not result in projectiles and violent energy release, which occur during an explosion.

6.54 SAFETY EXTRA LOW VOLTAGE CIRCUIT (SELV) – A circuit that exhibits voltages that are not in excess of those in Table 6.1 and are safe to touch both under normal operating conditions and after a single fault. An extra low voltage (ELV) is equivalent to SELV under normal conditions (not single fault) only.

**Table 6.1**
**SELV Voltage Limits**

| Voltage limits | |
|---|---|
| **Normal** | **Single fault** |
| Open circuit voltage with generally sinusoidal shape of 42.4 Vpeak, 30 Vrms or 60 Vdc | Open circuit voltage with generally sinusoidal shape of 42.4 Vpeak, 30 Vrms or 60 Vdc with excursions up to 71 Vpeak or 120 Vdc for periods up to 200 ms |
| In Canada, see 6.29. | |

6.55 SODIUM-BETA (HIGH TEMPERATURE) CELLS – Cells that utilize metallic sodium and ceramic beta-alumina solid electrolyte and that operate at elevated temperatures. The following are two commercial technologies under this group:

a) SODIUM NICKEL CHLORIDE CELL – A rechargeable cell that has sodium as its negative electrode, a positive electrode that may consist of nickel, nickel chloride or sodium chloride and a ceramic beta-alumina solid electrolyte. The normal operation of the cell is within a temperature range of 270 – 350 °C (518 – 662 °F) so that the active materials are in a molten state and to ensure ionic conductivity.

b) SODIUM/SULFUR CELLS – A rechargeable cell that has sodium as its negative electrode, a positive electrode that consists of sulfur, and a ceramic beta alumina electrolyte. The normal operation of the cells is within a temperature range of 310 – 370 °C (590 – 698 °F) so that the active materials are in a molten state and to ensure ionic conductivity.

6.56 SODIUM ION CELLS – Cells that are similar in construction to lithium ion cells except they utilize sodium as the ion of transport with a positive electrode consisting of a sodium compound, and carbon or similar type anode with an aqueous or non-aqueous electrolyte and with a sodium compound salt dissolved in the electrolyte.

NOTE: Examples of sodium ion cells are Prussian Blue cells or transition metal layered oxide cells.

6.57 STATE OF CHARGE (SOC) – The available capacity in a battery system, pack, module or cell expressed as a percentage of rated capacity.

6.58 THERMAL RUNAWAY – The incident when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion. The thermal runaway progresses when the cell's generation of heat is at a higher rate than the heat it can dissipate. This may lead to fire, explosion and gassing.

6.59 TOXIC VAPOR RELEASE – A release of vapor(s) in a concentration in excess of the Occupational Safety and Health Administration (OSHA) 8-h time-weighted-average (TWA) permissible exposure limit, which corresponds to the National Institute of Safety and Health (NIOSH) 10 h per day, 40 h per week permissible exposure limits.

In Canada, the limit values may vary between agencies.

6.60 VENTING – A condition when the cell electrolyte and/or battery/capacitor solvent is emitted as vapor, smoke or aerosol from a designed vent or through a sealing edge.

**CONSTRUCTION**

## 7 General

### 7.1 Non-metallic materials

7.1.1 Polymeric materials employed for enclosures shall comply with the requirements as outlined in the Enclosure Requirements table, Table 4.1, Path III, of UL 746C except as modified by this standard.

*Exception No. 1: Polymeric materials utilized for light electric rail (LER) enclosures for motive and VAP applications shall have a minimum flammability of V-1 or better, in accordance with UL 94 if intended for building into an enclosure or compartment within the train.*

*Exception No. 2: LER enclosure parts for motive and VAP applications may alternatively be evaluated to the 20 mm end-product flame tests in accordance with UL 746C.*

7.1.2 The factors taken into consideration when an enclosure is being judged are as follows. For a nonmetallic enclosure, all of these factors shall be considered with respect to thermal aging. Dimensional stability of a polymeric enclosure is addressed by compliance to the mold stress relief distortion test.

a) Resistance to impact;

b) Crush resistance;

c) Abnormal operations;

d) Severe conditions; and

e) Mold-stress relief distortion.

7.1.3 The polymeric materials employed as enclosures and insulation shall be suitable for the anticipated temperatures encountered in the intended application. Pack enclosures shall have a Relative Thermal Index (RTI) with impact suitable for temperatures encountered in the application but no less than 80 °C (176 °F), as determined in accordance with UL 746B.

7.1.4 The pack enclosure materials intended to be exposed to sunlight in the end use application shall comply with the UV Resistance and the Water Exposure and Immersion tests in accordance with UL 746C.

7.1.5 Polymeric materials used as direct support for live parts other than those circuits determined non-hazardous (i.e. limited power circuits) shall comply with the insulation requirements of UL 746C.

*Exception: Polymeric materials used as direct support for live parts that meet the requirements for “Safeguards Against Fire Under Normal Operating Conditions and Abnormal Operating Conditions,” Clause 6.3, of UL 62368-1/CSA C22.2 No. 62368-1, or the requirements for “Safeguards Against Fire Under Single Fault Conditions,” Clause 6.4, of UL 62368-1/CSA C22.2 No. 62368-1 are considered acceptable. Where specified in the reference document that components must meet the relevant IEC component standards, those components shall meet the applicable CSA or UL Standards.*

7.1.6 Polymeric tanks, piping and housings containing only electrolyte and sensors in flow batteries shall have a flammability rating of HB or better in accordance with UL 94.

7.1.7 Printed wiring boards shall have a flammability rating of V-0 or V-1 in accordance with UL 94.

*Exception: This requirement does not apply to printed wiring boards connected only in low-voltage, limited-energy circuits (LVLE) where the deterioration or breakage of the bond between a conductor and the base material does not result in a risk of fire or electric shock.*

7.1.8 Gaskets and Seals relied upon for safety shall be determined suitable for the temperatures they are exposed to and other conditions of use. Compliance is determined by the applicable tests of UL 157.

### 7.2 Metallic parts resistance to corrosion

7.2.1 Metal pack enclosures shall be corrosion resistant. A suitable plating or coating process can achieve corrosion resistance. Additional guidance on methods to achieve corrosion protection can be found in UL 50E/C22.2 No. 94.2.

7.2.2 Conductive parts in contact at terminals and connections shall not be subject to corrosion due to electrochemical action. Combinations above the line in Table D.1 of Annex D shall be avoided unless there is an evaluation that demonstrates that the potential for corrosion is negligible for the particular connection materials and design. See Annex D.

### 7.3 Enclosures

7.3.1 The enclosure of a battery system shall have the strength and rigidity required to resist the possible physical abuses that it will be exposed to during its intended use, in order to reduce the risk of fire or injury to persons. Compliance is determined by the tests of this standard.

7.3.2 A tool providing the mechanical advantage of a pliers, screwdriver, hacksaw, or similar tool, shall be the minimum mechanical capability required to open the enclosure.

7.3.3 Openings in the enclosure shall be designed to prevent inadvertent access to hazardous parts. Compliance is determined by the Tests for Protection Against Access to Hazardous Parts Indicated by the First Characteristic Numeral, Clause 12 of IEC 60529 or CAN/CSA-C22.2 No. 60529, for a minimum IP rating of IP2X or IPXXB, and C22.1, the Enclosure Selection Table for Nonhazardous Locations, Table 65. (Evaluation per IEC 60529 or CAN/CSA-C22.2 No. 60529, Clause 12, consists of the use of the IEC articulate probe applied with a force of 10 N ±10 %).

*Exception: For battery systems intended for location in restricted access locations only per 6.51, hazardous parts may be contacted with the articulate probe, but shall be located or guarded to prevent unintended contact by service or other trained personnel. Such equipment shall be provided with installation instructions in accordance with 45.3 and marked in accordance with 44.14.*

7.3.4 Openings in the enclosure shall be constructed to prevent accumulation of flammable gases that could lead to a hazardous condition from concentrations of hydrogen gas due to electrolysis of aqueous electrolytes for applicable battery technologies, such as vented or valve regulated lead acid and nickel batteries and applicable electrochemical capacitor technologies, greater than 25 % of the LFL of hydrogen (equivalent to 1 % concentration in a volume of air). Ventilation openings shall have a minimum opening area of:

$$A = 0.005NC_5\,(cm^2)$$

Where:

$A$ = Total cross sectional area of ventilation holes required ($cm^2$)

$N$ = Number of cells in battery

$C_5$ = Capacity of battery at the 5-h rate (Ah)

*Exception: The area of ventilation openings can be reduced if it can be demonstrated that there is sufficient ventilation within the battery to prevent hydrogen accumulations above 25 % of the LFL of hydrogen.*

7.3.5 Packs intended for installation where they may be exposed to moisture either through rain, splashing water or immersion shall be evaluated for their intended resistance to ingress of moisture in accordance with IEC 60529 or CAN/CSA-C22.2 No. 60529, or as outlined in NFPA 70, Article 110, or Section 2 of C22.1 for enclosure type designation and UL 50E/C22.2 No. 94.2, or NEMA 250. See also Section 39.

## 7.4 Wiring and terminals

### 7.4.1 General

7.4.1.1 Wiring shall be insulated and acceptable for the purpose, when considered with respect to temperature, voltage, and the conditions of service to which the wiring is likely to be subjected within the equipment.

7.4.1.2 A wiring splice or connection shall be mechanically secure and shall provide electrical contact without strain on connections and terminals. Wiring shall be secured and routed away from sharp edges or parts exceeding insulation. Openings in compartments through which insulated wiring is routed shall be smooth and well-rounded or provided with protective insulating bushings or grommet to prevent abrasion. Wiring connections between various parts of a battery module/pack and accessories shall be routed and secured to prevent the potential for short circuit conditions to occur.

7.4.1.3 An uninsulated live part, including a terminal, shall be secured to its supporting surface by a method other than friction between surfaces so that it will be prevented from turning, shifting in position, or creating short circuit.

7.4.1.4 An external battery terminal shall be designed to prevent inadvertent shorting. An external terminal shall be designed to prevent inadvertent misalignment or disconnection when installed in its end use application.

7.4.1.5 External non-detachable cords and leads that are accessible in the end use installation shall be provided with strain relief that prevents strain to internal conductors under pull and push-back conditions. Compliance is determined by the tests of 26.4 and 26.5.

7.4.1.6 Plugs and receptacles shall be rated for the intended voltage, current, temperature, and if applicable, for disconnect under load conditions.

7.4.1.7 Battery system cables shall be rated for their anticipated service including voltage, current, temperature and environment. External cords for hazardous voltage circuits shall be jacketed to prevent wear to internal conductors and rated and provided with insulation suitable for the intended applications.

7.4.1.8 In multiway plugs and sockets, and wherever shorting could otherwise occur, means shall be provided to prevent contact between parts in SELV circuits or parts at hazardous voltage due to loosening of a terminal or breaking of a wire at a termination. Compliance is checked by inspection, by measurement and, where necessary, by the following test. A force of 10 N (2.25 lbf) is applied to the conductor near its termination point. The conductor shall not break away or pivot on its terminal to the extent that spacings are reduced below the values specified in 7.5.

7.4.1.9 Wiring compartments and wiring terminals provided for connection of the battery system to external circuits shall be constructed as outlined below:

a) A field wiring compartment in which supply connections are to be made shall be located so that the connections will be accessible for inspection after the unit is installed as intended.

b) A knockout in a sheet-metal enclosure shall be secured and shall be removable without undue deformation of the enclosure. The knockout shall be surrounded by a flat surface to accommodate seating of a conduit bushing or locknut of the appropriate size.

c) An outlet box, terminal box, wiring compartment, in which field connections are made shall be free from any sharp edges including screw threads, a burr, a fin or moving part of the like that may abrade the insulation on conductor or otherwise damage wiring.

d) A field wiring terminal or lead shall be rated for the connection of a conductor or conductors having a minimum ampacity rating of 125 % of the rating of the unit.

e) The distance between the end of the connection point of a field installed wire and the wall of the enclosure toward which the wire is to be directed, shall be in accordance with Table 312.6 (A) or (B) of NFPA 70.

### 7.4.2 Beads and ceramic insulators

7.4.2.1 Beads and similar ceramic insulators on conductors shall:

a) Be so fixed or supported that they cannot change their position in such a way that a hazard would be created; and

b) Not rest on sharp edges or sharp corners.

7.4.2.2 If beads are located inside flexible metal conduits, they shall be contained within an insulating sleeve, unless the conduit is mounted or secured in such a way that movement in normal use would not create a hazard. Compliance is checked by inspection and, where necessary, by the following test. A force of 10 N (2.25 lbf) is applied to the insulators or to the conduit. The resulting movement, if any, shall not create a hazard in the meaning of this standard.

### 7.5 Spacings and separation of circuits

#### 7.5.1 General

7.5.1.1 Electrical circuits within the pack at opposite polarity shall be provided with reliable physical spacing to prevent inadvertent short circuits (i.e. electrical spacings on printed wiring boards, physical securing of un-insulated leads and parts, etc.). Insulation suitable for the anticipated temperatures and maximum voltages shall be used where spacings cannot be controlled by reliable physical separation.

7.5.1.2 Electrical spacings in circuits shall be based upon the grade of insulation required as outlined in the Insulation Materials and Requirements, Clause 5.4 of UL 62368-1/CSA C22.2 No. 62368-1, and shall comply with Clearances, Clause 5.4.2, and Creepage Distances, Clause 5.4.3, of UL 62368-1/CSA C22.2 No. 62368-1. For the appropriate pollution degree of the intended environment see 7.5.2 and 7.5.3.

*Exception No. 1: As an alternative to these spacing requirements, the spacing requirements in UL 840, may be used. For determination of clearances, a dc source such as a battery does not have an overvoltage category as outlined in the section for Components of UL 840 unless charged through an ac mains connected rectifier, then the overvoltage category should be the same as that required for the rectifier unless the rectifier uses galvanic isolation. If galvanic isolation is employed, then the overvoltage category can be reduced to the next lower overvoltage category. The anticipated pollution degree is determined by the design and application of the battery system or subassembly under evaluation.*

*Exception No. 2: As an alternative to the clearance values outlined in UL 62368-1/ CSA C22.2 No. 62368-1 the alternative method for determining minimum clearances in the Annex for Alternative Method for Determining Clearances for Insulation in Circuits Connected to an AC Mains not Exceeding 420 V peak (300 V RMS), Annex X, of UL 62368-1/CSA C22.2 No. 62368-1 may be applied.*

*Exception No. 3: As an alternative to these spacing requirements, the spacing requirements of Table 7.1 may be applied instead. When using this table, maximum working voltages of circuits can be determined through the test of Section 23. See the note in Table 7.1 regarding adjustment for spacings where double or reinforced insulation is required.*

*Exception No. 4: As an alternative, clearances and creepage distances per IEC 60664-1 can be applied instead.*

**Table 7.1**
**Electrical Spacings**

| Circuit ratings | Minimum spacings[a] | |
|---|---|---|
| | Through air | Over surface |
| | Between parts of opposite polarity, live and non-current carrying parts and live and ground connections | Between parts of opposite polarity, live and non-current carrying parts and live and ground connections |
| V | mm (in) | mm (in) |
| 30 – 50[b] | 1.6 (1/16) | 1.6 (1/16) |
| 51 – 150 | 3.2 (1/8) | 6.4 (1/4) |
| 151 – 300 | 6.4 (1/4) | 9.5 (3/8) |
| 301 – 660 | 9.5 (3/8) | 12.7 (1/2) |
| 661 – 1000 | 19.1 (3/4) | 19.1 (3/4) |
| 1001 – 1500 | 21.6 (7/8) | 30.5 (1-1/4) |

**Table 7.1 Continued on Next Page**

**Table 7.1 Continued**

| Circuit ratings | Minimum spacings[a] | |
|---|---|---|
| | Through air | Over surface |
| | Between parts of opposite polarity, live and non-current carrying parts and live and ground connections | Between parts of opposite polarity, live and non-current carrying parts and live and ground connections |
| V | mm (in) | mm (in) |

[a] The spacings in this table are suitable between live parts and conductive non-current carrying parts separated by basic insulation only or between basically insulated conductive non-current carrying parts and accessible parts separated by supplemental insulation. Spacings between hazardous voltage parts and accessible parts requiring double or reinforced insulation will require that the values outlined in the table be doubled. Refer to 7.6 regarding required insulation levels.

[b] Spacings at these voltages may be decreased from those indicated in the table if it can be determined through test or analysis that there is no hazard.

7.5.1.3 Conductors of circuits operating at different potentials shall be reliably separated from each other unless they are each provided with insulation acceptable for the highest potential involved.

7.5.1.4 An insulated conductor shall be reliably retained so that it cannot contact an uninsulated live part of a circuit operating at a different potential. Some examples include clamping or routing of conductors, use of separating barriers of insulating material or other means that provides permanent separation of the parts.

7.5.1.5 There are no minimum spacings applicable to parts where insulating compound completely fills the casing of a compound or subassembly if the distance through the insulation, at voltages above SELV levels is a minimum of 0.4-mm (0.02-in) thick for supplementary or reinforced insulation, and passes the Dielectric Voltage Withstand Test. There is no minimum insulation thickness requirement for insulation of circuits at or below SELV levels for basic or functional insulation. Some examples include potting, encapsulation, and vacuum impregnation.

7.5.1.6 UL 840 shall not be used for clearances between an uninsulated live part and the walls of a metal enclosure, including fittings for conduit or armored cable. UL 840 shall not be used for the clearance and creepage distance at field wiring terminals.

7.5.1.7 When determining the clearance for double or reinforced insulation in accordance with UL 840, the clearances of reinforced insulation shall be dimensioned corresponding to the rated impulse voltage, but choosing one step higher in the preferred series of values in the Minimum Clearances for Equipment table of UL 840 than that specified for basic insulation. If the impulse withstand voltage required for basic insulation, is other than a value taken from the preferred series, reinforced insulation shall be dimensioned to withstand 160 % of the impulse withstand voltage required for basic insulation.

7.5.1.8 When determining the creepage for double or reinforced insulation in accordance with UL 840, the creepage distances for reinforced insulation shall be twice the creepage distance required for the basic insulation as determined in UL 840.

7.5.1.9 When determining the electrical spacing according to 7.5.1.1, a battery circuit that has no direct connection to a primary circuit and derives its power from a transformer or converter shall be considered a secondary circuit. The phase-to-ground rated system voltage used in the determination of mains transient voltage in UL 62368-1/CSA C22.2 No. 62368-1 or the rated impulse voltage in UL 840 shall be the rated supply voltage of the charging equipment for the battery.

7.5.1.10 For batteries intended for installation at high altitudes (i.e. 2000 m and above), see the Multiplication Factors for Clearances and Test Voltages table of UL 62368-1/CSA C22.2 No. 62368-1 or the Altitude Correction Factors for Clearance Correction table of IEC 60664-1 for multiplication factors to be applied to clearance values.

### 7.5.2 Overvoltage categories applied for electrical creepage and clearance determination

7.5.2.1 When determining the creepage and clearance requirements from 7.5.1.2, the overvoltage categories for the battery systems shall be determined based on how the batteries are connected to the supply mains. For equipment or circuits energized from the mains, four categories are considered:

a) Category IV applies to equipment permanently connected at the origin of an installation (upstream of the main distribution board). Examples are electricity meters, primary overcurrent protection equipment and other equipment connected directly to outdoor open lines;

b) Category III applies to equipment permanently connected in fixed installations (downstream of, and including, the main distribution board). Examples are switchgear and other equipment in an industrial installation;

c) Category II applies to equipment not permanently connected to the fixed installation. Examples are appliances, portable tools and other plug-connected equipment; and

d) Category I applies to equipment connected to a circuit where measures have been taken to reduce transient overvoltages to a low level.

7.5.2.2 For stationary battery systems, Overvoltage Category III is applied. Overvoltage Category II may be applied for a stationary battery system that is isolated from an Overvoltage category III supply source (such as from an Overvoltage category III PCS) through an isolated transformer or protected in a manner that prevents transient overvoltage conditions. For vehicle auxiliary power batteries and on board LER batteries, Overvoltage Category II shall be applied.

### 7.5.3 Pollution degree for electrical creepage and clearance determination

7.5.3.1 With reference to 7.5.1.2, the following are conditions for determining the pollution degree to utilize when determining creepage and clearance distances. See also examples noted in Table 7.2.

a) Pollution Degree 1 – No pollution or only dry, non-conductive pollution. Normally, this is achieved by having components and subassemblies adequately enclosed by enveloping or hermetic sealing so as to exclude dust and moisture.

b) Pollution Degree 2 – Only non-conductive pollution that might temporarily become conductive due to occasional condensation.

c) Pollution Degree 3 – Subject to conductive pollution, or to dry non-conductive pollution which could become conductive due to expected condensation.

d) Pollution Degree 4 – Pollution that generates persistent conductivity through conductive dust or rain and snow.

**Table 7.2**
**Examples of the Provision of Pollution Degree Environments**

| Pollution degree | Method of achievement |
|---|---|
| PD3 | a) If installed outdoors, the use of an enclosure meeting IPX4 or Type 3R; or<br>b) If indoor installed, no climate conditioning provided to prevent condensation. |
| Reduction of PD3 to PD2 | a) Indoor installation with climate conditioning provided and where condensation is not expected; or<br>b) Outdoor installation provided with climate conditioning, which prevents condensation and conductive dust within an enclosure rated IPX4 or Type 3R; or<br>c) An enclosure meeting IP54 per IEC 60529 or Type 3 per UL 50E and no internally generated contamination; or<br>d) The use of an enclosure meeting IPX7 or IPX8 per IEC 60529 or Type 6 or Type 6P per UL 50E. |
| Reduction of PD2 to PD1 | With a PD2 environment, an enclosure subjected to an IP5X dust test of IEC 60529 or the outdoor test of UL 50E, Clause 8.4.1 and that has no internally generated contamination. |
| Reduction to PD1 | Control of the environment at the insulation surface to allow Pollution Degree 1 can be accomplished by the methods in UL 62368-1/CSA C22.2 62368-1 (for example, encapsulation, potting or coating) or conforming coating per UL 746E. |

## 7.6 Insulation levels and protective grounding and bonding

7.6.1 Hazardous voltage circuits shall be insulated from accessible conductive parts and circuits as outlined in 7.6.2 through the following:

a) Basic insulation and provided with a protective grounding system for protection in the event of a fault of the basic insulation; or

b) A system of double or reinforced insulation; or

c) A combination of (a) and (b).

7.6.2 Safety extra low voltage (SELV) circuits as defined in 6.54 that are insulated from accessible conductive parts through functional insulation only are considered accessible.

7.6.3 Batteries that rely upon protective grounding, shall comply with 7.6.4 – 7.6.9.

7.6.4 Accessible non-current carrying metal parts of a battery system with hazardous voltage circuits, that could become live in the event of an insulation fault, shall be bonded to the equipment ground terminal.

7.6.5 Parts of the protective grounding system shall be reliably secured in accordance with 7.4.1.2 and provided with good metal-to-metal contact. All connections shall be secured against accidental loosening and shall ensure a thoroughly good connection. The resistance between the protective conductive terminal of 7.6.8 and the accessible non-current carrying conductive parts outlined in 7.6.2 shall not exceed 0.1 Ω.

7.6.6 With reference to 7.6.5, when connecting conductive parts to be bonded, paint or coatings in areas of contact shall be removed or paint piercing lock washers shall be used with securement bolts or screws to provide good metal to metal contact. Thread-locking sealants, epoxies, glues, or other similar compounds, and solder alone shall not be used as a securement means as these are not considered reliable. In addition, rivets, hinges (unless metal-to-metal piano type hinges), and parts that may be removed as a result of servicing shall not be relied upon as connections for ensuring continuity of the protective grounding and bonding system.

7.6.7 With reference to 7.6.5, methods of securement considered reliable and ensuring good metal-to-metal contact can consist of the following methods:

a) Terminal blocks;

b) Pressure connectors, grounding lugs and similar grounding and bonding equipment connectors;

c) Exothermic welding processes;

d) Machine screw-type fasteners that engage not less than two threads or are secured with a nut; and

e) Thread-forming machine screws that engage not less than two threads in the enclosure.

7.6.8 The main ground terminal of the protective grounding system shall be identified by one of the following:

a) A green-colored, not readily removable terminal screw with a hexagonal head;

b) A green-colored, hexagonal, not readily removable terminal nut;

c) A green colored pressure wire connector; or

d) The word "Ground" or the letters "G" or "GR" or the grounding symbol (IEC 60417, No. 5019) or otherwise identified by a distinctive green color.

7.6.9 Conductors, relied upon for the protective grounding and bonding system, shall be sized to handle intended fault currents and if insulated, the insulation shall be green or green and yellow striped in color. Grounding conductors shall be sized in accordance with Article 250.122 of NFPA 70 or Rule 10-810 of C22.1.

## 7.7 Transformers

7.7.1 Transformers shall be evaluated in accordance with UL 1562, UL 1310 or an equivalent standard for overload conditions, and shall have suitable insulation for the circuits they are connected to.

7.7.2 Transformers in low voltage circuits can alternatively be evaluated in accordance with 26.6.

7.7.3 Transformers shall be provided with overcurrent protection on the primary side of the transformer and sized in accordance with Article 450 of NFPA 70 or Section 26 of C22.1.

## 7.8 System safety analysis

7.8.1 A safety analysis consisting of a hazard identification, risk analysis and risk evaluation shall be conducted on the device under test. This safety analysis shall determine which parts of the system are safety related through an existing methodology such as outlined 7.8.2. This approach should determine the hazard scenarios and define mitigation mechanisms. This safety analysis shall identify safety circuits or software that address each hazardous condition and consider the performance of each safety circuit or software. The following conditions in (a) – (c) shall be considered unless sufficient justification (e.g. additional safety analysis) is provided by the manufacturer that these conditions are not hazardous. The following conditions in (a) – (c) shall be considered at a minimum, but are not limited to:

a) Battery cell over-voltage and under-voltage;

b) Battery over-temperature and under-temperature; and

c) Battery over-current during charge and discharge conditions.

7.8.2 Documents that can be used as guidance for the safety analysis include:

a) IEC 60812;

b) IEC 61025;

c) MIL-STD-1629A; and

d) IEC 61508, all parts.

7.8.3 The analysis of 7.8.1 is utilized to identify anticipated faults in the system which could lead to a hazardous condition and is validated by compliance with 7.9. The analysis shall consider the reliability of any monitoring components and systems and any communication systems providing information to the controls that can affect safety. The analysis shall consider single fault conditions in the protection circuit in addition to single faults elsewhere that could lead to a hazardous condition.

## 7.9 Protective circuit and controls

7.9.1 Active protective devices shall not be relied upon for critical safety and shall comply with one of the following in (a) – (c) and comply with 7.9.2 and 7.9.3 as applicable. Refer to 6.49 and 6.50 for definitions of active and passive protective devices.

a) They are provided with a redundant passive protective device;

b) They are provided with redundant active protection that remains functional and energized upon loss of power to, or failure of the first level of active protection; or

c) They remain fully operational or fail safe upon loss of power to, or under a single fault condition of the active circuit.

*Exception : Active protective devices that comply with IEC 61508 (all parts), meeting minimum Safety Integrity Level (SIL) “2”, ISO 13849 (all parts), meeting minimum performance level (PL) “c”, or ISO 26262 (all parts), minimum of Automotive Safety Integrity Level (ASIL) “C” are permitted to be relied upon for critical safety. The SIL, PL, or ASIL for a safety function may be reduced if the manufacturer provides additional safety analysis, e.g. Layer of Protection Analysis (LOPA), showing that the required risk reduction level has been reduced by other measures used within the battery system.*

7.9.2 Active protective devices relied upon for safety as noted in 7.9.1, shall be evaluated in accordance with:

a) The Failure-Mode and Effect Analysis (FMEA) requirements in UL 991 (Section 7);

b) The Protection Against Internal Faults to Ensure Functional Safety requirements in UL 60730-1 or CAN/CSA E60730-1 (Clause H.27.1.2); or

c) The Protection Against Faults to Ensure Functional Safety requirements (Class B requirements) in CSA C22.2 No. 0.8 (Section 5.5) to determine compliance and identify tests necessary to verify single fault tolerance.

7.9.3 With reference to 7.9.1, software relied upon for safety shall comply with:

a) Software Class 1 requirements of UL 1998;

b) Software Class B requirements of CSA C22.2 No. 0.8; or

c) The Controls Using Software requirements (Software Class B requirements) in UL 60730-1 (Clause H.11.12) or CAN/CSA E60730-1.

7.9.4 Software and its associated hardware determined critical to safety that can be updated remotely shall meet the requirements outlined in UL 5500.

7.9.5 Battery systems shall be protected against all hazards identified in the safety system safety analysis of 7.8.

7.9.6 With reference to 7.9.5, if relied upon for maintaining the cells within their safe operating limits, the battery management system (BMS) shall maintain cells within the specified cell voltage and current limits to protect against overcharge and over-discharge. The BMS shall also maintain cells within the specified temperature limits providing protection from overheating and under temperature operation. When reviewing safety circuits to determine that cell operating region limits are maintained, tolerances of the protective circuit/component shall be considered in the evaluation. Components such as fuses, circuit breakers or other devices and parts determined necessary for safe operation of the battery system that are required to be provided in the end use installation, shall be identified in the installation instructions.

7.9.7 With reference to 7.9.5 and 7.9.6, if safe operating limits are exceeded, a protective circuit shall limit or shut down the charging or discharging to prevent excursions beyond these limits. When a hazardous scenario occurs, as determined in 7.8.1, the system shall continue to provide the safety function or go to a safe state (SS) or risk addressed (RA) state. If the safety function has been damaged, the system shall remain in the safe state or risk addressed state until the safety function has been restored and the system has been deemed safe to operate.

7.9.8 Solid state circuits and software controls, relied upon as the primary safety protection, shall be evaluated and tested to verify electromagnetic immunity in accordance with Section 27.

*Exception: Solid state circuits and software need not comply if it can be demonstrated that the solid state circuits and software are not relied upon as the primary safety protection.*

7.9.9 Battery systems with hazardous voltage circuits, including outputs of 60 V or greater, shall either be provided with a manual disconnect device or be provided with installation instructions for the disconnect device to be provided during installation of the system. The disconnect device shall be located as near as possible to the battery system terminals and it shall be rated for the application including disconnect under load if applicable. The disconnect device shall disconnect both poles of the circuit. The manual disconnect shall not require the use of a special tool or equipment to be operated. The disconnect device shall consist of either a manually operated switch or circuit breaker.

*Exception No. 1: A battery system having either a plug or receptacle or connector for connection to the output circuit may be provided without an additional disconnect means. The plug, receptacle and connectors used for this purpose shall be investigated in accordance with UL 1682 and rated for current interruption suitable for the circuit. The required spacing to the hazardous voltage circuits shall be maintained when the plug or receptacle or connector is disconnected.*

*Exception No. 2: A flow battery that can be turned off such that no circuits remain at hazardous voltage are not required to have a manual disconnect device.*

7.9.10 Fuses provided for battery overcurrent protection including short circuit protection shall be evaluated for both short circuit and overload conditions. Fuses that are evaluated for short circuit conditions only (type aR fuses), shall be provided with supplementary protection (e.g. the BMS) to ensure protection under overcurrent conditions in ranges below those covered by these types of fuses.

7.9.11 Protective components of battery modules intended for series connection in battery systems shall be rated for the maximum voltage of the intended battery system.

### 7.10 Cooling/thermal management system

7.10.1 Battery systems that rely upon integral thermal management systems to prevent overheating shall be designed to shutdown upon failure of the thermal management system unless it can be demonstrated, that the thermal management system failure does not result in a hazardous situation. Compliance is determined by the Failure of the Cooling/Thermal Stability System Test of Section 24.

7.10.2 Piping, hose, and tubing used to contain liquid shall be resistant to chemical degradation from the liquid it contains, as well as other liquids reasonably likely to contact such parts during expected life of the equipment. It shall have the strength and material characteristics necessary to withstand the anticipated mechanical and environmental stresses. Compliance is determined as outlined in 7.11.1.

7.10.3 With reference to 7.10.2, piping containing fluids in accordance with the scope of ASME B31.3, shall comply with the applicable requirements of that code. ASME B31.3 applies to piping that contains toxic fluids, flammable fluids, fluids damaging to human tissue, and nonhazardous fluids at pressures greater than 15 psi (105 kPa) or temperatures lower than −29 °C (−20 °F) or greater than 186 °C (366 °F).

7.10.4 Piping, hose, and tubing containing liquids, shall be routed and secured to prevent leakage that could result in a fire, explosion or shock hazard.

7.10.5 Fans or blowers utilized for air-cooling systems shall comply with the applicable requirements in UL 507.

*Exception: Fans located in SELV or ELV dc circuits need not be evaluated if shown to comply with the test of 26.1.*

7.10.6 Battery systems that rely on integral heaters to maintain operating temperatures of the battery system, shall be designed to shutdown upon failure of the heaters unless it can be demonstrated through fault analysis and if necessary an abnormal operation test, that the heater failure does not result in a hazardous situation.

7.10.7 Temperature controls for heaters used to maintain the operating temperature range of a battery system during cold ambient conditions shall be positioned such that they monitor the system temperature and are minimally affected by the outside ambient. For example, temperature controls or regulators should normally be located away from outside vents.

### 7.11 Electrolyte containment parts and parts subject to pressure

7.11.1 Parts that contain electrolyte, such as piping, hose, and tubing shall be resistant to chemical degradation from the electrolyte. Electrolyte containing parts shall have the strength and material characteristics necessary to withstand the anticipated mechanical and environmental stresses. Compliance is determined through review of material datasheets and where determined necessary, an immersion test (using the electrolyte as the test liquid) in accordance with the Volume Change Test after Immersion of UL 157 for elastomeric materials or the Test for Resistance of Polymeric Materials to Chemical Reagents in UL 746A for other than elastomeric materials, (same as ASMT D543, Test Method I), as applicable to the material and part being tested. Elastomeric parts in contact with electrolyte shall be subjected to the volume change and extraction test after 70-h immersion in the electrolyte in accordance with UL 157. The volume change shall be minus 1 to plus 25 % and extraction (change in weight) no greater than 10 %. Plastics other than elastomeric parts in contact with electrolyte shall be subjected to an immersion for 168 h at room temperature followed by a check for volume and weight change in accordance with ASTM D543, Procedure I method. The percentage of change of volume shall not be greater than 2 % of the original and the change in weight shall be no not increase more than 25 % or decrease more than 10 % of the original value.

*Exception No. 1: See Annex C for material requirements for flowing electrolyte systems.*

*Exception No. 2: Not applicable to individual cell or capacitor casings and materials that have been evaluated to appropriate component requirements per 7.12.*

7.11.2 Piping, hose, and tubing containing electrolyte, shall be routed and secured to prevent leakage that could result in a fire, explosion or shock hazard.

7.11.3 Parts under pressure shall be acceptable for the maximum anticipated pressure as determined by the tests of Section 36.

*Exception: See Annex C for material requirements for flowing electrolyte systems.*

7.11.4 Relief valves or rupture members relied upon to relieve overpressure conditions in a battery system shall operate in accordance with their specifications for start to discharge (i.e. pressure at which the relief valve or rupture membrane starts to relieve pressure). Compliance is determined by the tests of Section 37. This requirement does not apply to relief valves or rupture members integral to a cell or monobloc battery such as a VRLA type battery.

*Exception: Relief valves and ruptures members stamped with the ASME approval mark for the particular device in accordance with the ASME Boiler and Pressure Vessel Code need not be subjected to the tests of Section 37.*

7.11.5 A pressure-relief device shall have its discharge opening located and directed so that operation of the device will not deposit moisture on bare live parts or on insulation or components that could be detrimentally affected by the discharge. It shall have a start to discharge (i.e. pressure at which the relief valve or rupture membrane starts to relieve pressure) rating adequate to relieve the pressure.

7.11.6 The fill port of the electrolyte containment of a monobloc system shall be designed to prevent overfill and spillage of electrolyte during the electrolyte filling.

7.11.7 Flow batteries shall be provided with a means for spill control such as a spill containment system to prevent electrolyte spills. The spill containment shall be sufficient to handle electrolyte spills for the size of the system. See Spill Containment Systems, Section C6, for means to determine compliance.

7.11.8 Flowing electrolyte batteries shall be provided with a means of leak detection that shall identify when a leak occurs in the system and initiate controls to mitigate the leak condition.

## 7.12 Cells (battery and electrochemical capacitor)

7.12.1 Sealed nickel metal hydride cells shall comply with the cell tests of the Testing Required for Cells table of UL 2054 in addition to the requirements of this standard. Cells shall be provided with specifications for use (charging and discharging), installation, storage and disposal.

*Exception No. 1: The overall dimensions of the projectile test aluminum test screen may be increased from those outlined in UL 2054 to accommodate large cells intended for stationary and LER applications, but the flat panels of the test screen shall not exceed a distance of 305 mm (12 in) from the cell in any direction.*

*Exception No. 2: The overall external resistance for the short circuit test shall be less than or equal to 20 mΩ.*

*Exception No. 3: The crush test shall be a bar crush test rather than a flat plate crush using a bar with a 15-cm (5.9-in) diameter if the flat plate crush test per UL 2054 is insufficient to create a crush condition in the cell as determined by (a) – (c) below. The force shall be applied until one of the following occurs:*

*a) A voltage (OCV) drop of one-third of the original cell voltage occurs;*

*b) A deformation of 15 % or more of initial cell dimension occurs; or*

*c) A force of 1,000 times the weight of cell is reached.*

*Exception No. 4: Nickel metal hydride or nickel cadmium cells that are sealed and formed as part of a monobloc battery, need only comply with the requirements of this standard as part of the assembled battery. If provided with a pressure release vent or flame arrester, the nickel battery shall comply with the requirements outlined in 7.12.8.*

*Exception No. 5: Sample numbers tested for each test based upon UL 2054 test program may be reduced from 5 samples tested to 2 samples tested.*

*Exception No. 6: During the heating test, the samples are held for 30 min at the maximum temperature rather than 10 min.*

7.12.2 Secondary lithium cells shall comply with the requirements outlined in Annex E, and be marked as required in 44.15 and 44.16. Cells shall be provided with specifications as outlined in 45.7.

7.12.3 Secondary lithium cell design shall ensure sufficient safety measures to mitigate internal short circuits and other hazardous conditions during the life of the cells. Safety measures to maintain cell safety include, but are not limited to, the following:

a) The appropriate choice and placement of insulation. IEEE 1625 and IEEE 1725 provide guidance on placement and application of insulation within cells and general cell design safety considerations;

b) Sufficient sizing of the negative electrode active materials to cover the positive electrode active materials;

c) Proper placement of insulation and separation of parts at opposite polarity including insulation and placement of tabs to prevent inadvertent short circuits during the life of the cell;

d) The use of appropriate protection mechanisms such as separator shutdown, protective coatings and electrolyte additives, etc.; and

e) The use of separators with sufficient strength, thermal properties and that are sized to prevent short circuit between the positive and negative electrodes during charge and discharge over the life of the cells.

7.12.4 With reference to 7.12.3, compliance to (a) – (e) is determined through a review of the cell construction as part of a tear down analysis, a review of documentation on the cell construction and components, and the cell tests of Annex E.

7.12.5 Sodium-beta cells and batteries shall comply with the cell tests outlined in Annex B. Cells shall be provided with specifications for use (charging and discharging), installation, storage and disposal.

7.12.6 Flowing electrolyte stacks and battery systems shall comply with the requirements outlined in Annex C.

7.12.7 With reference to 7.12.6, flowing electrolyte battery systems shall be designed to mitigate shunt currents. Imbalance conditions and the potential for corrosion of the electrolyte containment parts may occur as a result of excessive shunt currents in a flowing electrolyte battery system. The flowing electrolyte battery manufacturer shall demonstrate through analysis and data that shunt currents have been mitigated as a result of the system design.

7.12.8 Batteries employing pressure release valves or flame arrestors shall comply with the pressure release test or the flame arrester test of UL 1989 in addition to the requirements of this standard. See Annex H for alternative criteria for vented or valve regulated lead acid or nickel cadmium batteries. Cells and multi-cell/monobloc batteries shall be provided with specifications for use (charging and discharging), installation, storage and disposal as outlined in Annex H.

7.12.9 Electrochemical capacitor cells and modules shall comply with the requirements outlined in UL 810A in addition to the requirements of this standard.

7.12.10 Sodium ion cells (e.g. Prussian Blue cells or transition metal layered oxide cells) shall comply with Annex E, and be marked as required in 44.15 and 44.16. Cells shall be provided with specifications as outlined in 45.7.

### 7.13 Repurposed cells and batteries

7.13.1 Batteries and battery systems using repurposed cells and batteries shall ensure that the repurposed parts have gone through an acceptable process for repurposing in accordance with UL 1974. See also 44.3.

## PERFORMANCE

### 8 General

8.1 Unless indicated otherwise the device under test (DUT) shall be at the maximum operational state of charge (MOSOC), in accordance with the manufacturer's specifications, for conducting the tests in this standard. After charging and prior to testing, the samples shall be allowed to rest for a maximum period of 8 h at room ambient.

*Exception: For secondary lithium ion cells or batteries in which temperature is not a dependency on the test, the rest time may be extended to 36 h, but shall not be less than 90 % MOSOC.*

8.2 Unless otherwise indicated, fresh samples (i.e. not more than 6 months old) representative of production shall be used for the system level tests described in Sections 15 – 42. The test program and number of samples to be used in each test is shown in Table 8.1.

*Exception No. 1: At the agreement of the manufacturer, DUT samples may be re-used for more than one test if not damaged in a manner that would affect test results. Minor repairs can be made to samples such as replacement of fuses, etc. in order to reuse samples for multiple tests.*

*Exception No. 2: For repurposed batteries and battery systems, the “repurposing manufacturing date” is the date of manufacture used to determine the 6 month threshold.*

## Table 8.1
## Tests and Sample Requirements for Battery Systems and Packs

| Test | Section | Number of samples[a] |
|---|---|---|
| **Electrical Tests** | | |
| Overcharge[c] | 15 | 1 |
| High Rate Charge[c] | 16 | 1 |
| Short Circuit[c] | 17 | 1 |
| Overload Under Discharge[c] | 18 | 1 |
| Overdischarge Protection[c] | 19 | 1 |
| Temperature and Operating Limits Check[c] | 20 | 1 |
| Imbalanced Charging[c] | 21 | 1 |
| Dielectric Voltage Withstand | 22 | 1 Use Temperature Sample |
| Continuity | 23 | 1 Use Temperature Sample |
| Failure of Cooling/Thermal Stability System[c] | 24 | 1 |
| Working Voltage Measurements[e] | 25 | 1 |
| Locked-Rotor Test (Low Voltage D.C. Fans/Motors In Secondary Circuits) | 26.1 | b |
| Input | 26.2 | b |
| Leakage Current | 26.3 | b |
| Strain Relief | 26.4 | b |
| Push-Back Relief | 26.5 | b |
| Low Voltage Transformer Evaluation | 26.6 | b |
| **Electromagnetic Immunity Tests** | | |
| Electrostatic Discharge | 27.2 | b |
| Radio-Frequency Electromagnetic Field | 27.3 | b |
| Fast Transient/Burst Immunity | 27.4 | b |
| Surge Immunity | 27.5 | b |
| Radio-Frequency Common Mode | 27.6 | b |
| Power Frequency Magnetic Field | 27.7 | b |
| Operational Verification | 27.8 | b, h |
| **Mechanical Tests** | | |
| Vibration (LER Motive and VAP Applications) | 28 | 1 |
| Shock (LER Motive and VAP Applications)[c] | 29 | 1 |
| Crush (LER Motive and VAP Applications)[c] | 30 | 1 |
| Static Force | 31 | 1 |
| Impact | 32 | 1 |
| Drop Impact (rack mounted module)[f] | 33 | 1 |
| Wall Mount Fixture/Handle Test[g] | 34 | 1 (mounting fixture) |
| Mold Stress | 35 | 1 |
| Pressure Release | 36 | b |
| Start-to-Discharge | 37 | b |
| **Environmental Tests** | | |
| Thermal Cycling (LER Motive and VAP Applications)[c] | 38 | 1 |
| Resistance to Moisture[c] | 39 | 1 |

**Table 8.1 Continued on Next Page**

**Table 8.1 Continued**

| Test | Section | Number of samples[a] |
|---|---|---|
| Salt Fog[c] | 40 | 1 |
| External Fire Exposure for Projectile Hazards Test[c] | 41 | 1 |
| **Tolerance To Internal Cell Failure Tests** | | |
| Single Cell Failure Design Tolerance[c] | 42 | 1 |
| **Material Tests** | | |
| 20-mm end product flame test (LER Motive and VAP Applications) (Note: not conducted if minimum V-1) | 7.1.1 | b |
| Parts in contact with electrolyte | 7.11.1 | d |

[a] See Exception No. 1 in 8.2 for re-use of samples for tests.
[b] Need only evaluate parts/area under test and not complete battery system.
[c] Testing may be conducted on subassemblies if determined representative of the complete battery system.
[d] Parts or samples in accordance with ASTM test methods.
[e] This check of maximum working voltage values is needed when using the spacing criteria of Table 7.1.
[f] This test is conducted on modules or subassemblies intended for field installation in rack-mount or similar equipment.
[g] This test is conducted on battery system with wall-mount fixtures only.
[h] Operational Verification conducted on all samples used in 27.2 – 27.7.

8.3 All tests, unless noted otherwise, are conducted in a room ambient 25 ±5 °C (77 ±9 °F). Tests shall be conducted with the DUTs heated to normal operating temperatures unless indicated otherwise in the test. For those tests that require the DUT to reach thermal equilibrium, thermal equilibrium is considered to be achieved if after three consecutive temperature measurements taken at intervals of 10 % of the previously elapsed duration of the test but not less than 15 min, indicate no change in temperature greater than ±2 °C (3.6 °F).

8.4 Thermocouples shall be attached to the central component cell or module during the system level tests in Sections 15 – 42. Temperatures shall also be measured on any components affected by temperature in the control circuit during the tests of 9.1 and 9.2. Temperature shall be measured using thermocouples consisting of wires not larger than 24 AWG (0.21 mm$^2$) and not smaller than 30 AWG (0.05 mm$^2$) connected to a potentiometer-type instrument. Temperature measurements shall be made with the measuring junction of the thermocouple held tightly against the component/location being measured.

8.5 Unless noted otherwise in the individual test methods, the tests shall be followed by a 1-h observation time prior to concluding the test and temperatures shall be monitored in accordance with 10.2.

## 9 Determination of Potential for Fire Hazard

9.1 In addition to visible signs of fire, non-compliant test results for fire shall also include an evaluation for combustible vapor concentrations during testing if there is the potential for combustible vapor concentrations based upon the technology and design of the battery system. For detection of potential combustible vapor concentrations that may be emitted during testing, a gas monitor suitable for detecting 25 % of the lower flammability limit (LFL) of the evolved gases being measured. A minimum of two sampling locations where concentrations may occur such as at vent openings or vent ducts shall be used for taking measurements.

*Exception: As an alternative to using gas detection measurement to determine if there are combustible vapor concentrations, non-compliant tests results for fire may include an evaluation for potential combustible vapor concentrations with the use of a minimum of two continuous spark sources. The continuous spark sources shall provide at least two sparks per second with sufficient energy to ignite* *natural gas and shall be located near anticipated sources of vapor such as vent openings or at the vent duct.*

9.2 Additional precautions shall be taken during tests requiring this analysis due to the potential for combustible vapor concentrations that may occur within the test room or chamber.

## 10 Important Test Considerations

10.1 The tests contained in this standard may result in explosions, fire and emissions of combustible and/or toxic vapors, leakage of hazardous chemicals as well as electric shock. It is important that personnel use extreme caution when conducting any of these tests and that they be protected from flying fragments, leaked electrolyte, explosive force, toxic vapors and chemicals and sudden release of heat and noise that could result from testing. To prevent injury, protective equipment and clothing should be utilized when handling batteries and when conducting testing. Short-circuiting can lead to very hazardous currents, and large format batteries may still be hazardous even in an uncharged condition. The test area shall be well ventilated to protect personnel from possible harmful vapors or gases and care should be taken to prevent exposure to leaked electrolyte. Test facilities shall be equipped to contain, mitigate, and exhaust toxic vapors and particulate matter, leaked electrolyte and other hazardous substances that may be generated during the tests of this standard including the External Fire Exposure Test of Section 41. See also 9.2.

10.2 As an additional precaution, the temperatures on surfaces of the DUT shall be monitored during the tests per 8.5. All personnel involved in the testing of battery systems shall be instructed to never approach the DUT until temperatures are falling and are at safe levels.

## 11 Single Fault Conditions

11.1 Where there is a specific reference to a single fault condition in the individual test methods, the single fault shall consist of a single failure (i.e. open, short or other failure means) of any component in the electrical energy storage system that could occur as identified in the system safety analysis of 7.8 and that could affect the results of the test.

## 12 Test Results

12.1 Tests that result in one or more of the following conditions as noted in Table 12.1 and as defined in Section 6, shall be considered as non-compliant for the test. Additional details of passing results criteria are provided in the individual test methods.

**Table 12.1**
**Non-Compliant Test Results**

| Tests[a] | Non-compliant results |
|---|---|
| Overcharge | E, F, C, V, S, L, R, P |
| High Rate Charge | E, F, C, V, S, L, R, P |
| Short Circuit | E, F, C, V, S, L, R, P |
| Overload Under Discharge | E, F, C, V, S, L, R, P |
| Overdischarge Protection | E, F, C, V, S, L, R, P |
| Temperature and Operating Limits Check | E, F, C, V, S, L, R, P |
| Imbalanced Charging | E, F, C, V, S, L, R, P |

**Table 12.1 Continued on Next Page**

**Table 12.1 Continued**

| Tests[a] | Non-compliant results |
|---|---|
| Failure of Cooling/Thermal Stability System | E, F, C, V, S, L, R, P |
| Electrostatic Discharge | E, F, C, V, S, L, R, P |
| Radio-Frequency Electromagnetic Field | E, F, C, V, S, L, R, P |
| Fast Transient/Burst Immunity | E, F, C, V, S, L, R, P |
| Surge Immunity | E, F, C, V, S, L, R, P |
| Radio-Frequency Common Mode | E, F, C, V, S, L, R, P |
| Power Frequency Magnetic Field | E, F, C, V, S, L, R, P |
| Operational Verification | E, F, C, V, S, L, R, P |
| Vibration (LER Motive and VAP Applications) | E, F, C, V, S, L, R, P |
| Shock (LER Motive and VAP Applications) | E, F, C, V, S, L, R, P |
| Crush (LER Motive and VAP Applications) | E, F, C, V |
| Static Force | E, F, C, V, S, L, R, P |
| Impact | E, F, C, V, S, L, R, P |
| Drop Impact | E, F, C, S, L, R, P |
| Thermal Cycling (LER Motive and VAP Applications) | E, F, C, V, S, L, R, P |
| Resistance to Moisture | E, F, C, V, S, L, R, P |
| Salt Fog | E, F, C, V, S, L, R, P |
| External Fire Exposure for Projectile Hazards Test | E |
| Single Cell Failure Design Tolerance[b] | E, F |

Non-compliant Results Key:

E – Explosion

F – Fire

C – Combustible vapor concentrations

V – Toxic vapor release[c] (in buildings or LER passenger compartments)

S – Electric shock hazard (dielectric breakdown)

L – Leakage (external to enclosure of DUT)

R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3)

P – Loss of protection controls[d]

[a] For tests that evaluate one specific part of the DUT such as the mold stress, continuity, dielectric voltage withstand, working voltage measurements, wall mount fixture, pressure release, start-to-discharge, and the Section 26 tests on electric components; only those compliance criteria noted in the tests method need be applied. See also individual tests for additional results criteria details.

[b] During the single cell failure design tolerance test, an internal fire shall not spread to outside of the DUT enclosure.

[c] A toxic vapor release is a hazard if there is potential for persons to be exposed to it. Toxic vapor release is defined in 6.59 for all tests with the exception of the crush test. In the case of the crush test for an LER application, toxic vapor release is considered to have occurred with the release of vapor(s) in a concentration in excess of the Emergency Response Planning Guidelines ERPG Level 2. ERPG-2 defines this as: "The maximum airborne concentration below, which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action." See Section 13.

[d] Loss of protection controls – Failure of software and/or electronic controls, discrete control devices or other built-in electrical protection components relied upon for safety and that remain in the circuit during the test, to operate as intended.

12.2 For the following tests, if the DUT is still operational after the test (a user replaceable fuse may be replaced or user resettable device such as an accessible circuit breaker, etc. reset), it shall be subjected to a minimum single charge/discharge cycle in accordance with the manufacturer's specifications. No non-compliant results as outlined in Table 12.1 shall occur during the charge/discharge cycle of a still operational DUT.

a) Overcharge;

b) Short Circuit;

c) Overdischarge Protection;

d) Imbalanced Charging;

e) Failure of Cooling/Thermal Stability System;

f) Electrostatic Discharge;

g) Radio-Frequency Electromagnetic Field;

h) Fast Transient/Burst Immunity;

i) Surge Immunity;

j) Radio-Frequency Common Mode;

k) Power Frequency Magnetic Field;

l) Operational Verification;

m) Vibration;

n) Shock;

o) Impact or Drop Impact;

p) Static Force;

q) Thermal Cycling;

r) Salt Fog; and

s) Resistance to Moisture.

NOTE: If the tests of (f) – (l) may be done on the battery management system only and not the whole battery system.

## 13 Determination of Toxic Emissions

13.1 For those systems for which venting from cells or capacitors could result in the emission of toxic gases as determined by an analysis of the outgassed substances, the concentration of toxic gases during the destructive testing noted in Table 12.1 shall be monitored using one of the sampling methods noted below and as outlined in 13.2. Analysis of the outgassed substances can be obtained through review of MSDS sheets and/or analysis of the outgassed substances. If it can be determined through examination of the cells after testing that they did not vent as a result of the test, the system is in compliance with these criteria.

a) ASTM D4490;

b) ASTM D4599;

c) OSHA Evaluation Guidelines for Air Sampling Methods Utilizing Spectroscopic Analysis; or

d) NIOSH Manual of Analytic Methods.

13.2 To determine the concentration of toxic emissions, testing shall be conducted in a closed test chamber of known volume large enough to contain the DUT. Results obtained from continuous sampling the emissions during testing shall be scaled to estimate the anticipated exposure and concentration of toxic materials within either the passenger compartment of a light electric rail (LER) or the anticipated smallest room in which the system can be installed. For walk-in units, continuous monitoring shall also be conducted in the interior of the system enclosure. The results for stationary applications shall be further scaled to consider a 0.5 air changes per hour (ACH) ventilation rate. The 0.5 ACH represents allowable low ventilation rated for construction.

*Exception: Stationary systems intended for installation outdoors only and that are not walk-in units are exempted from this monitoring. Stationary systems and systems for LER applications are also exempted from these requirements if provided with a ventilation system or otherwise designed to prevent exposure to toxic vapor releases and vents vapors to a safe location.*

## 14 Measurement Equipment Accuracy

14.1 Unless noted otherwise in the test methods, the overall accuracy of measured values of test specifications or results when conducting testing in accordance with this standard, shall be within the following values of the measurement range:

a) ±1 % for voltage;

b) ±3 % for current;

c) ±4 % for watts;

d) ±2 °C (±3.6 °F) for temperatures at or below 200 °C (392 °F), and ±3 % for temperatures above 200 °C (392 °F);

e) ±0.1 % for time;

f) ±1 % for dimension;

g) ±3 % for Ah;

h) ±4 % for Wh.

# ELECTRICAL TESTS

## 15 Overcharge Test

15.1 The purpose of this test is to evaluate a battery system's ability to withstand an overcharge condition.

15.2 A fully discharged DUT (i.e. discharged to the manufacturer's specified EODV) shall be subjected to an overcharge resulting from a single fault condition in the charging protection/control circuit of the system that could lead to an overcharge condition. See Section 11 for a description of a single fault condition. Single fault conditions can be applied to both passive and active protective devices. During test, the voltage of the cells shall be measured. The test supply equipment used for charging the DUT shall be sufficient to create an overcharge of the DUT to at least 110 % of the maximum specified charging voltage. The charging rate used shall be the manufacturer’s specified maximum charging rate.

*Exception No. 1: Overcharge testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.*

*Exception No. 2: Components in circuits evaluated for reliability (i.e. evaluated for functional safety in accordance with 7.9) need not be subjected to single fault conditions.*

15.3 The test shall continue until ultimate results occur followed by an observation period per 8.5. Ultimate results are considered to have occurred when one of the following occurs:

a) The sample charging is terminated by the protective circuitry whether it is due to voltage or temperature controls or if the DUT reaches 110 % of its maximum specified charging voltage limit. Exceeding the manufacturer's specified charging limit is considered a non-compliant result. The DUT is monitored per 8.5 and 10.2; or

b) Battery system failure occurs as evidenced by explosion, fire or other identifiable non-compliant results per Table 12.1.

15.4 During the test, detection methods as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

15.5 If the DUT is operational after the overcharge test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.

15.6 At the conclusion of the observation period, the samples shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

15.7 As a result of the overcharge test, the maximum charging voltage measured on the cells or modules shall not exceed their normal operating region. Also, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 16 High Rate Charge

16.1 The purpose of this test is to evaluate a battery system's ability to protect against a high rate charge condition at currents over the battery maximum charging current specification.

16.2 A fully discharged DUT (i.e. discharged to the manufacturer's specified EODV) shall be subjected to a high rate charge. There shall be a single fault condition on overcurrent charge protection devices or controls unless they have been evaluated for reliability (i.e. evaluated for functional safety in accordance with 7.9). During the test, the current and voltage of the cells shall be measured. The test supply equipment used for charging the DUT shall be sufficient to provide a current that is 20 % greater than the maximum specified charging rate for the batteries.

*Exception: High rate charge testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.*

16.3 The high rate charging of the DUT shall continue until ultimate results occur followed by an observation period per 8.5. Ultimate results are considered to have occurred when one of the following occurs:

a) The sample charging is terminated by the protective circuitry whether it is due to current, voltage or temperature controls. The DUT is monitored per 8.5 and 10.2; or

b) Battery system failure occurs as evidenced by explosion, fire or other identifiable non-compliant results per Table 12.1.

16.4 During the test, detection methods as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

16.5 If the DUT is operational after the high rate charge test, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.

16.6 At the conclusion of the observation period, the samples shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

16.7 As a result of the high rate charge test, the battery protection circuit (e.g. BMS) shall detect the overcharging current and shall prevent the battery from being charged over the maximum battery charging current. The following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 17 Short Circuit Test

17.1 This test shall be conducted on a fully charged DUT (MOSOC per 8.1) with parallel connected cells or modules to determine its ability to withstand an external short circuit. DUTs with only series connections (i.e. no parallel connections of cells or modules) are tested at the cell or module level if determined to be equivalent to testing at the system level.

*Exception: Short circuit testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.*

17.2 The sample shall be short-circuited by connecting the positive and negative terminals of the sample with a shorting device having resistance as low as practicable. In all cases the resistive circuit load shall have a maximum total resistance of 20 mΩ, as measured from the DUT terminals. For battery systems, the short circuit discharge profile at the terminals for current and time shall be recorded and compared with the manufacturer's specified value in 44.4.

17.3 The direct short circuit test shall also be conducted on the battery module if it is intended to be installed or replaced in the field. The output of the battery module sample shall be short-circuited with a shorting device having resistance as low as practicable with a maximum total resistance of 20 mΩ.

17.4 Tests shall be conducted at room ambient. The samples shall reach thermal equilibrium temperature as outlined in 8.3 before the terminals are connected.

17.5 The sample shall be completely discharged (i.e. discharged until near zero state of charge/its energy is depleted), or protection in the circuit has operated and the temperature on the center module has peaked or reached a steady state condition and 7 h has elapsed, or a fire or explosion has occurred.

17.6 During the test, samples supplied with protective devices shall be subjected to a single component fault using any single fault condition that may be determined to occur during discharge conditions. See Section 11 for details regarding single fault conditions. Single fault conditions can be applied to both passive and active protective devices.

*Exception: Components in circuits evaluated for reliability (i.e. evaluated for functional safety criteria considering single fault conditions in accordance with 7.9) need not be subjected to single fault conditions.*

17.7 During the test, a detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

17.8 If the DUT is operational after the short circuit test it shall be subjected to a charge and discharge cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.

17.9 At the conclusion of the observation period , the samples shall be subjected to the "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

17.10 As a result of the short circuit test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

*Exception: For modules that do not have integral short circuit protection controls, the compliance criteria is (a) and (b) above only.*

17.11 For battery systems, the measured maximum short circuit current and duration at that maximum value shall not be greater than the specified value of 44.4.

## 18 Overload Under Discharge

18.1 This test shall be conducted on a fully charged DUT (MOSOC per 8.1) with parallel connected cells or modules to determine its ability to withstand an overload discharge condition. DUTs with only series connections (i.e. no parallel connections of cells or modules) may be tested at the cell or module level if determined to be equivalent to testing at the system level.

*Exception: Overload under discharge testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.*

18.2 Condition 1 is the overload above the specified maximum discharge current of the battery, but below the BMS overcurrent protection (secondary protection) in accordance with 18.3 – 18.5.

18.3 With reference to 18.2, the positive and negative terminals of the DUT is to be connected to the external discharging equipment. The fully charged DUT shall then be discharged at a current equal to 90 % of the rated overcurrent protection value of the BMS (secondary protection).

18.4 With reference to 18.2, the test shall be continued until:

a) The DUT has been completely discharged (i.e. discharged until near zero state of charge/its energy is depleted);

b) The protection in the circuit has operated and the temperature on the center cell/module has peaked or reached a steady state condition and 7 h has elapsed; or

c) A fire or explosion has occurred.

*Exception: The overload condition 1 can be waived if the maximum discharge current of the battery is equal to or higher than 90 % of the overcurrent protection value of the BMS (secondary protection).*

18.5 With reference to 18.2, during the test, samples supplied with protective devices in the discharge circuit shall be subjected to a single component fault using any single fault condition that may be determined to occur during discharge conditions. See Section 11 for details regarding single fault conditions. Single fault conditions can be applied to both passive and active protective devices.

*Exception: Overcurrent protection components in circuits evaluated for reliability (i.e. evaluated for functional safety criteria considering single fault conditions in accordance with 7.9) need not be subjected to single fault conditions.*

18.6 Condition 2 is the overload above the BMS overcurrent protection, but below the primary overcurrent protection in accordance with 18.7 – 18.9.

18.7 With reference to 18.6, the positive and negative terminals of the DUT shall be connected to the external discharging equipment. The DUT shall then be discharged at a current equal to 135 % of the main fuse rating.

*Exception No. 1: If the secondary overcurrent protection is a contactor, switch or similar disconnecting device, which has been investigated for an overload current higher than 135 % of the primary overcurrent protector rating, then the test shall be conducted at a discharge current of 150 % of the primary overcurrent protector rating.*

*Exception No. 2: If the secondary overcurrent protection has be investigated for an overload current higher than 150 % of the primary overcurrent protector rating, then the condition 2 test can be waived.*

18.8 With reference to 18.6, the test shall be continued until:

a) The DUT has been completely discharged (i.e. discharged until near zero state of charge/its energy is depleted);

b) The protection in the circuit has operated and the temperature on the center cell/module has peaked or reached a steady state condition and 7 h has elapsed; or

c) A fire or explosion has occurred.

18.9 With reference to 18.6, during the test, samples supplied with protective devices in the discharge circuit shall be subjected to a single component fault using any single fault condition that may be determined to occur during discharge conditions. See Section 11 for details regarding single fault conditions. Single fault conditions can be applied to both passive and active protective devices.

*Exception: Overcurrent protection components in circuits evaluated for reliability (i.e. evaluated for functional safety criteria considering single fault conditions in accordance with 7.9) need not be subjected to single fault conditions.*

18.10 During the test, a detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

18.11 If the DUT is operational after the short circuit test, it shall be subjected to a charge and discharge cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 shall then be conducted.

18.12 At the conclusion of the observation period, the samples shall be subjected to the "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

18.13 As a result of the overload test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 19 Overdischarge Protection Test

19.1 This test shall be conducted on a fully charged sample (MOSOC per 8.1) to determine the DUTs ability to withstand an overdischarge condition and is conducted with all discharge protection circuitry for both temperature and minimum voltage connected to prevent irreparable cell damage. During the test, active protective devices shall be subjected to single fault conditions, unless the protection circuit has been tested for functionality in accordance with 7.9. During test, the voltage of the cells shall be measured.

*Exception: Overdischarge protection testing on a subassembly may be conducted instead of the complete battery system if determined to be representative of the battery system.*

19.2 The DUT shall be subjected to a constant discharging current/power that will discharge a battery at the manufacturer's specified maximum discharge rate. The test will continue until the passive protection device(s) are activated, or the minimum cell voltage/maximum temperature protection is activated, or the DUT has been discharged for an additional 30 min after it has reached its specified normal discharge limit, whichever comes first.

19.3 During the test, a detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations as determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

19.4 If the DUT is operational after the overdischarge protection test it shall be subjected to a charge and discharge cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.

19.5 At the conclusion of the observation period, the samples shall be subjected to the "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

19.6 As a result of the overdischarge protection test, the minimum discharge voltage measured on the cells shall not exceed their normal operating range. Also, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 20 Temperature and Operating Limits Check Test

20.1 This test is conducted to determine whether or not the cells/modules of the DUT are being maintained within their specified operating limits (including voltage and current at specified temperature) during maximum charge and discharge conditions. During this test, it shall also be determined as to whether or not temperature sensitive safety critical components are being maintained within their temperature ratings based upon the maximum operating temperature specifications of the DUT as well as a determination that temperatures on accessible surfaces are not exceeding safe limits.

*Exception: Temperature and operating limits check test on a subassembly may be conducted instead of a complete battery system if determined to be representative of the battery system.*

20.2 A fully discharged DUT (i.e. discharged to EODV) shall be conditioned within a chamber set to the upper limit charging temperature specifications of the DUT. After being stabilized at that temperature (refer to 8.3), the DUT shall be connected to a charging circuit input representative of anticipated maximum charging parameters. The DUT shall then be subjected to maximum normal charging while monitoring voltages and currents on modules until it reaches the manufacturer's specified fully charged condition. Temperatures shall be monitored on temperature sensitive components including cells.

*Exception No. 1: If the DUT is unable to be tested in a chamber, it can be tested at an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F). If tested at ambient temperatures during the test, the temperature measurement T shall not exceed:*

$$T \leq T_{max} - (T_{ma} - T_{amb})$$

*Where:*

*T is the temperature of the given part measured under the prescribed test.*

*$T_{max}$ is the maximum temperature specified for compliance with the test.*

*$T_{amb}$ is the ambient temperature during the test.*

*$T_{ma}$ is the maximum ambient temperature permitted by the manufacturer's specification or 25 °C (77 °F), whichever is greater.*

*Exception No. 2: If the design of the DUT and its controls result in worse case normal charging conditions when testing at ambient (i.e. due to thermostats or other controls lowering the charge levels at elevated ambient), the test shall be conducted at ambient temperature of 25 °C ±5 °C (77 °F ±9 °F). Temperatures on temperature sensitive components shall not exceed $T_{max}$.*

20.3 While still in the conditioning chamber, the chamber temperature shall be set to the upper limit discharging temperature specifications of the DUT if different from the charging temperature. The fully charged DUT (MOSOC per 6.1) shall then be discharged in accordance with the manufacturer's maximum rate of discharge down to the manufacturer's specified end of discharge condition while monitoring voltage and current on modules. Temperatures shall be monitored on temperature sensitive safety critical components including cells. Temperatures on accessible surfaces are also monitored.

*Exception No. 1: If the DUT is unable to be tested in a chamber, it can be tested at an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F). If tested at ambient temperatures during the test, the temperature measurement T shall not exceed:*

$$T \leq T_{max} - (T_{ma} - T_{amb})$$

*Where:*

> *T is the temperature of the given part measured under the prescribed test.*
>
> $T_{max}$ *is the maximum temperature specified for compliance with the test.*
>
> $T_{amb}$ *is the ambient temperature during the test.*
>
> $T_{ma}$ *is the maximum ambient temperature permitted by the manufacturer's specification or 25 °C (77 °F), whichever is greater.*

*Exception No. 2: If the design of the DUT and its controls result in worse case normal discharging conditions when testing at ambient (i.e. due to thermostats or other controls lowering the discharge rate at elevated ambient), the test shall be conducted at ambient temperature of 25 °C ±5 °C (77 °F ±9 °F). Temperatures on temperature sensitive components shall not exceed* $T_{max}$.

20.4 The charge and discharge cycles are then repeated for a minimum of two complete cycles of charge and discharge. The DUT is then subjected to an observation period per 8.5.

20.5 At the conclusion of the observation period, the samples shall be subjected to the "as received" dielectric voltage withstand test in accordance with Section 22 if it anticipated that there has been deterioration of the insulation during the temperature test. The DUT shall be examined for signs of rupture and evidence of leakage.

20.6 The manufacturer's specified operating limits for cells/modules (voltage, current at specified temperatures) shall not be exceeded during the charging and discharging cycles. Temperatures measured on components shall not exceed their specifications. Temperatures measured on accessible surfaces shall not exceed allowed limits. See Table 20.1 and Table 20.2 for temperature limit tables. Additional non-compliant results during the temperature test are as noted below in (a) – (h). For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); and

h) P – Loss of protection controls.

**Table 20.1**
**Temperature Limits – Components**

| Part | Maximum temperature, $T_{max}$ °C (°F) |
|---|---|
| Synthetic rubber or PVC insulation and external wiring | |
| – without temperature marking | 75 (167) |
| – with temperature marking | The temperature marking |
| Components, insulation, and thermoplastic materials | a |
| Cell casing | b |

[a] Temperatures measured on components and materials shall not exceed the maximum temperature rating for that component or material including internal cells.

[b] The cell casing temperature shall not exceed the manufacturer's recommended maximum temperature.

**Table 20.2**
**Temperature Limits – Surfaces**

| Accessible surface | Maximum temperature, $T_{max}$ °C (°F) | |
|---|---|---|
| | Metal | Plastic[a] |
| Accessible parts held continuously during normal use | 55 (131) | 75 (167) |
| Accessible surfaces held or touched for short periods only | 60 (140) | 85 (185) |
| Accessible surfaces which may be touched | 70 (158) | 95 (203) |

[a] Temperatures measured on accessible plastic enclosure surfaces shall not exceed the temperature ratings of the materials.

## 21 Imbalanced Charging Test

21.1 This test is to determine whether or not a battery system with series connected cells/modules can maintain the cells/modules within their specified operating parameters if it becomes imbalanced.

*Exception No. 1: Testing may be conducted at a subassembly level if that is representative of the battery system.*

*Exception No. 2: Testing may be conducted on an alternate configuration if it can be shown to be representative for the battery system.*

21.2 A fully charged DUT (MOSOC per 8.1) shall have all of its modules/cells with the exception of one discharged to its specified fully discharged condition. The undischarged module/cell shall be discharged to approximately 50 % of its specified state of charge (SOC) to create an imbalanced condition prior to charging.

21.3 The sample shall then be charged in accordance with the manufacturer's maximum normal charging specifications. Charging shall continue until end of charge conditions and the DUT reaches thermal equilibrium. The voltage of the partially charged module/cell shall be monitored during the charging to determine if its voltage limits are being exceeded. During the test, active protective devices shall be subjected to single fault conditions, unless the protective circuit has been tested for functionality in accordance with 7.9.

21.4 During the test, a detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations as determined necessary. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

21.5 If the DUT is operational after the test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.

21.6 At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

21.7 The maximum voltage limit of the module/cell shall not be exceeded when charging an imbalanced DUT. Also, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 22 Dielectric Voltage Withstand Test

22.1 This test is an evaluation of the electrical spacings and insulation at hazardous voltage circuits within the battery system.

22.2 Circuits exceeding 42.4 V peak or 60 Vdc shall be subjected to an electric strength test in accordance with UL 62368-1/CSA C22.2 No. 62368-1, Clause 5.4.9.

*Exception: Semiconductors or similar electronic components liable to be damaged by application of the test voltage may be bypassed or disconnected.*

22.3 The test voltage shall be applied between the hazardous voltage circuits of the DUT and non-current carrying conductive parts that may be accessible and low voltage circuits separated from hazardous voltage circuits by reinforced or double insulation.

22.4 The test voltage is also to be applied between the hazardous voltage charging circuit and the enclosure/accessible non-current carrying conductive parts of the DUT.

22.5 If the accessible parts of the DUT are covered with insulating material that may become live in the event of an insulation fault, then the test voltages are applied between each of the live parts and metal foil in contact with the accessible parts.

22.6 The test voltages shall be applied for a minimum of 1 min between all the hazardous circuits of the battery and accessible parts or circuits. Technologies that are required to be at an elevated operating temperature in order to be active, such as sodium-beta chemistries, shall be in a hot state prior to disconnection and applying the test potential.

22.7 There shall be no evidence of a dielectric breakdown (breakdown of insulation resulting in a short through insulation/arcing over electrical spacings) as evidenced by an appropriate signal from the dielectric withstand test equipment as a result of the applied test voltage. Corona discharge or a single momentary discharge is not regarded as an dielectric breakdown (i.e. insulation breakdown).

22.8 If the battery system contains hygroscopic materials that may affect spacings, this test is repeated with the DUT or with the subassembly of the DUT containing the hygroscopic materials subjected to humidity conditioning of UL 62368-1/CSA C22.2 No. 62368-1, Clause 5.4.8. As a result of this testing, there shall be no dielectric breakdown as outlined in 22.7.

## 23 Continuity Test

23.1 This test evaluates the continuity of the protective grounding and bonding system of the battery system that is intended to provide an electrically conductive path from the point of a ground fault on a battery system or its representative parts or components through normally non-current-carrying conductors, equipment, or the earth to the electrical supply source.

23.2 An alternate test method outlined in 23.7 may be used if the construction of the protective grounding and bonding system adheres to the construction methods outlined in 7.6.5 – 7.6.7. If the connections means vary from that outlined in 7.6.6 and 7.6.7, the fault current method outlined in 23.3 – 23.6 is the default method for evaluating the suitability of the protective grounding system.

23.3 The grounding system of an battery system shall have no more than 0.1-Ω resistance between any two parts of the system that are measured in accordance with the continuity test of 23.4 and 23.5.

23.4 The voltage drop in a protective grounding system is measured after applying a test current of 200 % of the rating of the overcurrent protection device rating, for a duration corresponding to 200 % of the time-current characteristic of the overcurrent protection device. If the duration for 200 % is not given, a point closest on the time-current characteristic shall be used. The overcurrent protective device limits the fault current in the protective grounding system, and is either provided in the battery system or external to the battery system and specified in the installation instructions. The supply used to provide the test current shall have a no load voltage not exceeding 60 Vdc.

23.5 The voltage drop measurement is made between any two conductive parts of the grounding system.

23.6 The resistance shall be calculated from the measured voltage drop and current. The determined resistance shall be less than or equal to 0.1 Ω.

23.7 To check the continuity of the bonding connections, the resistance can be measured between two points on the bonding connections using a milli-ohmmeter. The measured resistance between any two bonding connections shall be less than or equal to 0.1 Ω.

## 24 Failure of Cooling/Thermal Stability System

24.1 The purpose of this test is to determine if the battery system can safely withstand a failure in the cooling/thermal stability system.

*Exception: Testing may be conducted at a subassembly level if that is representative of the battery system.*

24.2 The DUT shall be fully discharged to the manufacturer's end of discharge condition EODV and then conditioned at maximum specified operating ambient for a period of 7 h or until thermally stable per 8.3, whichever is shorter. While still in the conditioning chamber, the DUT, with its cooling/thermal stability system disabled shall then be charged at its maximum specified charge rate until completely charged or until operation of a protective device.

24.3 The DUT shall be fully charged (MOSOC per 8.1) and then conditioned at maximum specified operating ambient for a period of 7 h or until thermally stable per 8.3, whichever is shorter. While still in the conditioning chamber, the DUT, with its cooling/thermal stability system disabled shall then be discharged at the maximum discharge rate until it reaches its specified end of discharge condition or until operation of a protective device.

24.4 During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

24.5 If the DUT is operational after the test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.

24.6 At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test per Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

24.7 The test method of 24.2 – 24.6 shall be repeated with the DUT conditioned at the minimum specified operating ambient.

24.8 As a result of the failure of cooling/thermal stability test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 25 Working Voltage Measurements

25.1 This test is to measure the working voltage of a battery system.

25.2 The working voltage between live parts of opposite polarity, live and dead metal parts, live parts and a metal enclosure, and live and ground connections under both normal charging and discharging conditions as specified by the manufacture is measured.

25.3 The dead metal parts and metal enclosure shall be assumed to be connected to the negative terminal of the system for testing purpose.

25.4 The values obtained during the measurements outlined in 25.2 shall be used to verify electrical spacings criteria per 7.5.

## 26 Tests on Electrical Components

### 26.1 Locked-rotor test for low voltage dc fans/motors in secondary circuits

26.1.1 The purpose of this test is to determine if a low voltage dc fan or motor does not present a hazard in a locked rotor condition. Fans complying with UL 507 are considered to comply with this requirement without test.

26.1.2 A sample of the fan or motor is placed on a wooden board, which is covered with a single layer of tissue paper, and the sample in turn is covered with a single layer of bleached cotton cheesecloth of approximately 40 g/$m^2$.

26.1.3 The sample is then operated at the voltage used in its application and with its rotor locked for 7 h or until steady conditions are established per 8.3, whichever is the longer.

26.1.4 There shall be no ignition of the tissue paper or cheesecloth.

### 26.2 Input

26.2.1 The input current draw of a control or accessory separate from the pack such as a mains supplied control or an accessory control evaluated independent from a system, shall be subjected to the input test of 26.2.2.

26.2.2 The current or watts input to an ac mains supplied unit, when connected to an ac supply adjusted to the test voltage specified in Table 26.1 shall not be more than 110 % of the rated/specified value. The current or watts input draw of a dc supplied unit, when connected to a dc supply, shall not exceed the rated/specified value of the device.

**Table 26.1**
**AC Test Voltages**

| Device rating (Vac) | Test supply voltage (Vac) |
|---|---|
| 110 – 120 | 120 |
| 220 – 240 | 240 |
| 254 – 277 | 277 |
| 380 – 415 | 415 |
| 440 – 480 | 480 |
| 560 – 600 | 600 |

### 26.3 Leakage current

26.3.1 For separate controls or other accessories of the system that are cord connected and supplied by ac mains circuits, the controls shall comply with the Protective Touch Voltage, Touch Current and Protective Conductor Current test of UL 62368-1/CSA C22.2 No. 62368-1, Clause 5.7.

### 26.4 Strain relief test

26.4.1 The purpose of this test is to determine if the strain relief means for a non-detachable accessible cord prevents damage or displacement upon being pulled.

26.4.2 The battery system or accessory provided with a strain relief shall withstand without damage to the cord or conductors and without displacement, a direct pull of 156 N (35 lbf) applied to the cord for 1 min. Supply connections within the equipment shall be disconnected from terminals or splices during the test when applicable. If the strain relief is mounted in a polymeric enclosure or part, the test is conducted after the mold stress test after the part has cooled to room temperature.

26.4.3 As a result of the pull force, there was no damage or displacement of internal connectors. Inner conductors may not elongate more than 2 mm (0.08 in) from the pre-test position.

### 26.5 Push-back relief test

26.5.1 The purpose of this test is to determine if the strain relief of a non-detachable accessible cord provides adequate protection to connections and prevent hazardous displacement of internal wiring and connections as a result of push back.

26.5.2 A product shall be tested in accordance with 26.5.3 and 26.5.4 without occurrence of any of the following conditions:

a) Subjecting the supply cord to mechanical damage;

b) Exposing the supply cord to a temperature higher than that for which it is rated;

c) Reducing spacings (such as to a metal strain-relief clamp) below the minimum required values; or

d) Damaging internal connections or components.

26.5.3 The supply cord shall be held 25.4 mm (1 in) from the point where the cord or lead emerges from the product and is then to be pushed back into the product. When a removable bushing, which extends further than 25.4 mm (1 in) is present, the bushing shall be removed prior to the test.

26.5.4 When the bushing is an integral part of the cord, then the test shall be carried out by holding the bushing. The cord shall be pushed back into the product in 25.4-mm (1-in) increments until the cord buckles or the force to push the cord into the product exceeds 26.7 N (6 lbf).

26.5.5 The supply cord shall be manipulated to determine compliance with 26.5.1.

26.5.6 If the strain relief is mounted in a polymeric enclosure or part, the test is conducted after the mold stress test after the part has cooled to room temperature.

### 26.6 Low voltage transformer evaluation

26.6.1 The purpose of this test is to determine that transformers located in low voltage circuits (i.e. ≤ 60 Vdc) do not present a fire hazard under overload conditions. Transformers complying with UL 1310 or equivalent standard and evaluated under overload conditions are considered to comply with these requirements without further testing.

26.6.2 If the tests in this section are conducted under simulated conditions on the bench, these conditions shall include any protection device that would protect the transformer in the complete equipment. Tests shall be conducted under ambient laboratory conditions. A sample of the transformer is placed on a wooden board, which is covered with a single layer of tissue paper, and the sample in turn is covered with a single layer of bleached cotton cheesecloth of approximately 40 $g/m^2$ (1.18 $oz/yd^2$).

26.6.3 If a transformer has more than one secondary winding or a tapped secondary winding, separate tests shall be conducted for each winding, or each section of a tapped winding, with the other windings loaded or unloaded as may occur in service unless it can be determined that one condition will produce the most unfavorable results.

26.6.4 A resistive load that will draw three times the normal input current or maximum obtainable output current, whichever is less, shall be connected directly to the transformer secondary winding with the transformer connected to the voltage of the circuit the transformer will be installed in. The transformer shall be operated continuously:

a) Until ultimate conditions are observed, including opening of a thermal cutoff or a similar device;

b) For 7 h if temperatures stabilize or cycling of an automatically reset protector occurs; or

c) For 50 cycles of resetting a manually reset protector.

26.6.5 As a result of the overload test, there shall be no emission of molten metal or fire as evidenced by burning or charring of the cheesecloth indicator or tissue paper.

## 27 Electromagnetic Immunity Tests

### 27.1 General

27.1.1 Active protective devices (e.g. battery management systems, solid state circuits, software controls, etc.) relied upon as the primary safety protection in 7.8 – 7.9 shall demonstrate sufficient immunity to electromagnetic interference by complying with the tests specified in 27.2 – 27.7. Alternate test procedures and levels specified in other standards may be used, but only if they are equivalent or more severe than the test procedures and levels specified below.

27.1.2 Each test shall begin with an operational DUT. The DUT may consist of only the battery management system, if that is the only part of the battery system that will be impacted.

27.1.3 During specific tests as indicated in 27.2 – 27.7, the DUT shall be subjected to a charge/discharge cycle in accordance with the manufacturer's specification. No non-compliant results as outlined in Table 12.1 shall occur during the charge/discharge cycle.

*Exception: It is acceptable if the charge/discharge cycle is not completed at the conclusion of the test.*

27.1.4 After each test in 27.2 – 27.7, the DUT shall be inspected to verify that it is still operational and in compliance with Table 12.1. This may require Operational Verification (27.8) of the DUT if it is not possible to determine that it is fully operational by inspection. If the DUT is no longer operational, a failure analysis shall be conducted to determine the reason for the failure and to verify that the DUT has failed safely in accordance with Table 12.1. A DUT that is no longer operational shall not be used on any remaining test.

27.1.5 In addition, after all tests in this section have been completed, all samples used during the tests specified in 27.2 – 27.7 shall comply with the Operational Verification in 27.8.

**27.2 Electrostatic discharge**

27.2.1 The DUT shall demonstrate immunity to electrostatic discharges in accordance with the test procedure specified in IEC 61000-4-2.

27.2.2 The following test levels shall be used:

a) ±6 kV contact discharge; and

b) ±8 kV air discharge.

27.2.3 After the test, the DUT shall comply with 27.1.4.

**27.3 Radio-frequency electromagnetic field**

27.3.1 The DUT shall demonstrate immunity to radio-frequency electromagnetic fields in accordance with the test procedure specified in IEC 61000-4-3.

27.3.2 The following test levels shall be used:

a) 10 V/m from 80 MHz to 1 GHz, 1 kHz (80 % AM); and

b) 3 V/m from 1.4 GHz to 6.0 GHz, 1 kHz (80 % AM).

27.3.3 During the test, the DUT shall comply with 27.1.3.

27.3.4 After the test, the DUT shall comply with 27.1.4.

**27.4 Fast transient/burst immunity**

27.4.1 The DUT shall demonstrate immunity to electrical fast transients/bursts in accordance with the test procedure specified in IEC 61000-4-4.

27.4.2 The following test levels in (a) – (c) shall be used. If the DUT has a DC power input port connected to an AC/DC converter such as a power supply or charger that is an integral part of the battery pack, the test shall be conducted on the AC input of the AC/DC converter using the test level specified in (c). Otherwise, the test shall be conducted on the DC power input port of the DUT using the test level specified in (b).

a) On signal/control ports intended to be connected to cables longer than 3 m (118 in), ±1 kV (5/50 ns, 5 kHz); capacitive clamp shall be used;

b) On input and output DC ports, ±1 kV (5/50 ns, 5 kHz); and

c) On input and output AC ports, ±2 kV (5/50 ns, 5 kHz).

27.4.3 After the test, the DUT shall comply with 27.1.4.

**27.5 Surge immunity**

27.5.1 The DUT shall demonstrate immunity to surges in accordance with the test procedure specified in IEC 61000-4-5.

27.5.2 The following test levels in (a) – (c) shall be used. If the DUT has a DC power input port connected to an AC/DC converter such as a power supply or charger that is an integral part of the battery pack, the test shall be conducted on the AC input of the AC/DC converter using the test level specified in (c). Otherwise, the test shall be conducted on the DC power input port of the DUT using the test level specified in (b).

a) For I/O signal/control ports intended to be connected to long-distance cables longer than 30 m (98.4 ft), which leave the building, and/or are for outdoor use, ±1 kV line-to-ground;

b) For input and output DC ports, ±0.5 kV line-to-line, and ±1 kV line-to-ground; and

c) For input and output AC ports, ±1 kV line-to-line, and ±2 kV line-to-ground.

27.5.3 After the test, the DUT shall comply with 27.1.4.

## 27.6 Radio-frequency common mode

27.6.1 The DUT shall demonstrate immunity to radio-frequency conducted disturbances in accordance with the test procedure specified in IEC 61000-4-6.

27.6.2 The following test levels in (a) – (c) shall be used. If the DUT has a DC power input port connected to an AC/DC converter such as a power supply or charger that is an integral part of the battery pack, the test shall be conducted on the AC input of the AC/DC converter using the test level specified in (c). Otherwise, the test shall be conducted on the DC power input port of the DUT using the test level specified in (b).

a) For I/O signal/control ports intended to be connected to cables longer than 3 m (118 in), 10 V (150 kHz to 80 MHz, 1 kHz, 80 % AM);

b) For input and output DC ports, 10 V (150 kHz to 80 MHz, 1 kHz, 80 % AM); and

c) For input and output AC ports, 10 V (150 kHz to 80 MHz, 1 kHz, 80 % AM).

27.6.3 During the test, the DUT shall comply with 27.1.3.

27.6.4 After the test, the DUT shall comply with 27.1.4.

## 27.7 Power-frequency magnetic field

27.7.1 The DUT shall demonstrate immunity to power-frequency magnetic fields in accordance with the test procedure specified in IEC 61000-4-8.

27.7.2 The test level of 10 A/m shall be used.

27.7.3 During the test, the DUT shall comply with 27.1.3.

27.7.4 After the test, the DUT shall comply with 27.1.4.

## 27.8 Operational verification

27.8.1 After the tests in 27.2 – 27.7 have been completed, all samples used during these tests shall comply with the following.

27.8.2 The manufacturer shall declare the anticipated performance of all safety functions performed by active protective devices.

27.8.3 The manufacturer shall provide test procedures to verify that each of the safety functions performed by active protective devices is working correctly. This may include, for example, execution of a full charge/discharge cycle, or verification of correct safety function performance by simulation.

27.8.4 The test procedures specified in 27.8.3 shall be performed with each DUT in the following conditions:

a) Fully-charged; and

b) Fully-discharged.

27.8.5 During the test procedures specified in 27.8.3 – 27.8.4, each DUT shall exhibit one of the following behaviors:

a) No loss of safety functions; or

b) Transition to an appropriate state to ensure safe operation of the DUT. This could include a DUT that has lost its ability to charge or discharge as long as safety is maintained.

27.8.6 If redundant methods of protection are provided for a safety function to comply with 7.9.1, each method of protection shall be evaluated to determine if it functions as intended.

## MECHANICAL TESTS

### 28 Vibration Test (LER Motive and VAP Applications)

28.1 The purpose of this test is to determine the battery system's resistance to anticipated vibration in LER motive and VAP installations and applies only to those systems intended for installation in these applications.

28.2 The sample shall be secured to the testing machine by means of a rigid mount, which supports all mounting surfaces of the sample.

*Exception: The sample may be mounted within a mounting fixture representative of the intended end use application.*

28.3 The fully charged sample (MOSOC per 8.1) shall be subjected to a vibration test in accordance with the Simulated Long Life Testing at Increased Random Vibration Levels Tests of IEC 61373, for the appropriate Category and Class of equipment as determined by the intended rail installation. (Category and Class of equipment is defined in IEC 61373.)

*Exception: Batteries intended for VAP applications shall be subjected to the Vibration Endurance Test of UL/ULC 2271 or UL/ULC 2580.*

28.4 The DUT shall be subjected to vibration in 3 mutually perpendicular directions. During the test the OCV of the DUT and temperatures on the center cell/module shall be monitored for information purposes.

28.5 During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

28.6 If the DUT is operational after the test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. See 12.2 for details regarding user resettable devices. An observation period per 8.5 is then conducted.

28.7 At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

28.8 As a result of the vibration test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 29 Shock Test (LER Motive and VAP Applications)

29.1 The purpose of this test is to determine the battery system's resistance to anticipated shock in LER motive and VAP installations and applies only to those systems intended for installation in these applications.

29.2 The sample shall be secured to the testing machine by means of a rigid mount, which supports all mounting surfaces of the sample. During the test, temperatures on the center module are monitored for information purposes.

*Exception No. 1: This sample may be mounted within a mounting fixture representative of the intended end-use rail application.*

*Exception No. 2: Batteries intended for VAP applications shall be subjected to the Shock Test of UL/ULC 2271 or UL/ULC 2580.*

29.3 A fully charged sample (MOSOC per 8.1) shall be subjected to a shock test in accordance with IEC 61373 for the appropriate Category and Class of equipment as determined by the intended rail installation. (Category and Class of equipment is defined in IEC 61373.)

*Exception: This test may be conducted at the module level if it can be shown that testing shall be representative of the battery system.*

29.4 Both positive and negative direction shocks shall be applied in each of 3 mutually perpendicular directions for a total of 18 shocks.

29.5 During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

29.6 If the DUT is operational after the test it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.

29.7 At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

29.8 As a result of the shock test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 30 Crush Test (LER Motive and VAP Applications)

30.1 This test is conducted on a fully charged battery system intended for LER motive and VAP applications to determine its ability to withstand a crush that could occur during an accident and applies only to those systems intended for installation in these applications.

30.2 A sample shall be crushed between a fixed surface and a ribbed test platen in accordance with the test fixture described in SAE J2464, with the following exceptions as noted below. Packs with 3 axes of symmetry, are subjected to 3 mutually perpendicular directions of press. A different sample of the DUT may be used for each crush.

*Exception No. 1: The maximum force applied to the DUT shall be 100 ±6 kN.*

*Exception No. 2: Battery systems with only 2 axes of symmetry, such as cylindrical designs are subjected to 2 mutually perpendicular directions of press.*

*Exception No. 3: The DUT may be installed in a protective framework representative of what is provided in the end use application.*

*Exception No. 4: A subassembly may be tested instead of a complete battery system if it can be demonstrated to be equivalent to testing a complete battery system.*

30.3 A detection method as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations within the sample. Venting of gases may occur, but shall not exceed ERPG-2 levels using the measurement methods outlined in Section 13. The sample shall be subjected to an observation period and the examined.

30.4 As a result of the crush test, the following in (a) – (d) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release.

## 31 Static Force Test

31.1 The purpose of this test is to determine if the enclosure has sufficient strength to safely withstand a static force that may be applied to it.

31.2 The enclosure of a fully charged DUT (MOSOC per 8.1) shall withstand a steady force of 250 N ±10 N for a period of 5 s, applied in turn to the top, bottom and sides of the enclosure fitted to the DUT, by means of a suitable test tool providing contact over a circular plane surface 30 mm (1.2 inch) in diameter. However, this test is not applied to the bottom of an enclosure having a mass of more than 18 kg (39.7 lbs). If the DUT is operational after completion of the application of the static force, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.

31.3 If deemed necessary (i.e. due to design of system and anticipation of venting of cells), one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

31.4 After the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

31.5 As a result of the static force test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

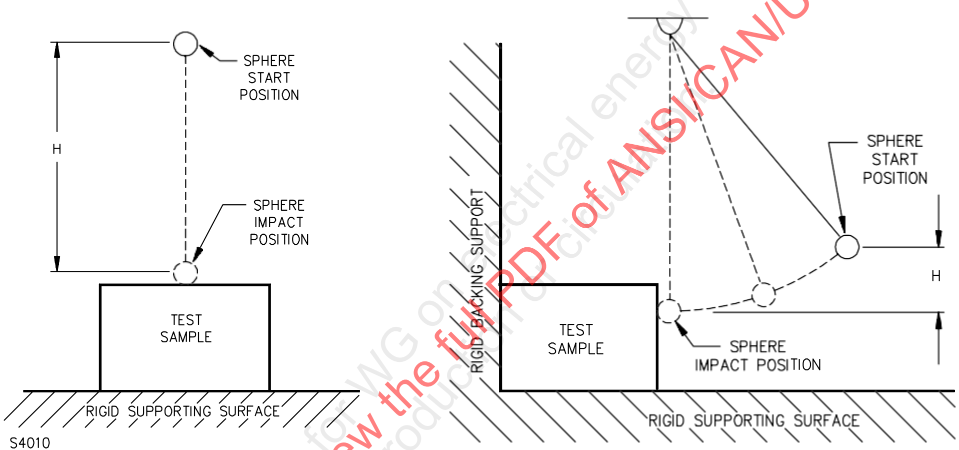
## 32 Impact Test

32.1 The purpose of this test is to evaluate the mechanical integrity of the enclosure and its ability to provide mechanical protection to the battery system contents.

32.2 A fully charged sample (MOSOC per 8.1) shall be subjected to a minimum of three impacts of 6.8 J (5 ft-lb) on any surface that can be exposed to a blow during intended use. The impact shall be produced by dropping a steel sphere, 50.8 mm (2 inches) in diameter, and weighing 535 g (1.18 lb) from a height, H, of 1.29 m (50.8 in). For surfaces other than the top of an enclosure, the steel sphere shall be suspended by a cord and swung as a pendulum, dropping through the vertical height of 1.29 m (50.8 in), with the product being impacted placed against a restraining vertical wall. See Figure 32.1. A different sample may be used for each impact.

**Figure 32.1**

**Impact Test**




– H in figure indicates the vertical distance the sphere must travel to produce the desired impact, 1.29 m (50.8 in).

– For the ball-pendulum impact test the sphere shall contact the test sample when the string is in the vertical position as shown.

– The DUT shall rest on a concrete floor. An equivalent non-resilient supporting surface may be used.

– The backing surface shall consist of 19-mm (3/4-in) plywood over a rigid surface of concrete.

32.3 If the DUT is operational after the impacts it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.

32.4 During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

32.5 After the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

32.6 As a result of the impact test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 33 Drop Impact Test

33.1 Modules that are intended for field installation into rack mount or similar equipment are subjected to a drop impact test to determine that no hazard exists as a result of an inadvertent drop during installation or removal.

33.2 After being equilibrated at room temperature per 8.3, a fully charged module/component pack shall be dropped from a minimum height of 100 cm (39.4 in) for products weighing 7 kg (15.4 lbs) or less, 10 cm (3.9 in) for products weighing >7 kg (15.4 lbs), but less than 100 kg (220.5 lbs), and 2.5 cm (0.98 in) for products weighing > 100 kg (220.5 lbs), to strike a concrete or metal surface in the position most likely to produce adverse results and in a manner most representative of what would occur during maintenance and handling/removal of the battery system during installation and servicing. The orientation of the drop shall be determined by the testing personnel from an analysis of the installation and servicing instructions. If using a metal test surface, it should be provided with some manner of insulation such as insulating film that will prevent inadvertent short circuiting to the surface but will not affect test results.

33.3 The sample shall be dropped a minimum of one time. However, if only one drop test is performed, it shall not be a flat drop. If one drop test is a flat drop, then at least one other test shall be performed that is not a flat drop.

33.4 The concrete surface shall be at least 76-mm (3-in) thick and the concrete or metal drop surface shall be large enough in area to cover the DUT.

33.5 After the drop, if the DUT is operational it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.

33.6 At the conclusion of the observation period, an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

33.7 A spark ignition source or gas monitoring as outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations within the sample immediately after the drop and repeated in the instance of increasing temperatures.

33.8 As a result of the drop impact test, the following in (a) – (g) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) S – Electric shock hazard (dielectric breakdown);

e) L – Leakage (external to enclosure of DUT);

f) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3); and

g) P – Loss of protection controls.

## 34 Wall Mount Fixture/Support Structure/Handle Test

34.1 A wall mounting apparatus of a wall mounted battery system, a battery support structure such as a stationary battery system rack, the support structure for a flow batteries stack(s), or a handle(s) provided for handling of a field/rack installed module/pack, shall have sufficient strength to support the battery system or allow for carrying of module/pack. Compliance is determined by the test below.

*Exception: This test can be waived for a battery rack complying with UL 2416 and rated for the intended weight of the batteries to be supported.*

34.2 The wall mounting apparatus or other support structure and battery system shall be installed in accordance with the manufacturer's specifications. A force equal to three times the weight of the battery system is additionally applied to the center of the mounting apparatus or support structure in a downward direction. The force shall be held for 1 min. For modules/packs with a carrying handle(s), the DUT shall be supported by the carrying handles and a force equal to three times the weight of the DUT is additionally applied in a downward direction. If more than one carrying handle is provided, the added weight shall be distributed between the handles.

34.3 As a result of the applied force, there shall be no damage to the mounting apparatus or support structure and the securement means when testing the wall mounting fixture or supporting structure. As a result of the applied force, there shall be no damage to handles or the handle mounting/securement means of the DUT.

## 35 Mold Stress Test

35.1 The purpose of this test is to determine if an enclosure made from molded polymeric material can withstand an accelerated aging test without compromising the safety of the enclosure.

35.2 One complete fully discharged sample (discharged to the manufacturer's specified EODV) shall be placed in a full-draft circulating-air oven maintained at a uniform temperature of at least 10 °C (18 °F) higher than the maximum temperature of the enclosure measured during the Temperature and Operating

Limits Check Test in Section 20, but not less than 70 °C (158 °F). The sample shall remain in the oven for 7 h.

35.3 After removal from the oven the DUT shall be subjected to an observation period per 8.5. After the observation period, the sample shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

35.4 As a result of the mold stress conditioning, the sample shall show no evidence of mechanical damage, such as cracking of the enclosure exposing hazardous parts or reducing electrical spacings or leakage of electrolyte from the enclosure.

## 36 Pressure Release Test

36.1 The purpose of this test is to ensure that the resettable pressure relief valve operates to prevent damage to the battery system and its electrolyte containment. This test is applicable to valve regulated technologies such as valve regulated lead acid batteries and for nickel systems with resettable relief valves.

36.2 A sample of the battery/cell shall be submerged in a container of mineral oil. For large batteries only the pressure relief valve needs to be submerged.

36.3 A charging current shall be caused to flow at an increased rate (to be specified by the manufacturer) until bubbles are observed to rise from the pressure relief valve.

36.4 Results are acceptable if gas is released normally and the electrolyte containment system does not rupture or leak and the DUT's casing is not ruptured.

## 37 Start-To-Discharge Test

37.1 The purpose of this test is to determine the average start to discharge pressure of a resettable pressure relief valve not provided with an ASME stamp and rating.

37.2 A calibrated pressure gauge having a range of at least 150 % of the anticipated maximum working pressure of the pressure relief valve shall be installed to indicate pressures developed within the battery system during test.

37.3 To determine the start-to-discharge pressure setting of a pressure-relief valve, each of three samples of the valve shall be subjected three times to a gradually increasing air pressure. The pressure at which the valve begins to open shall be recorded. The start-to-discharge pressure setting of each sample is considered to be the average value of the three trials.

37.4 The start-to-discharge value mentioned in 37.3 is the highest average value for the three samples tested.

37.5 The start-to-discharge pressure shall be in the range of 90 – 100 % of its assigned start-to-discharge pressure setting.

## ENVIRONMENTAL TESTS

### 38 Thermal Cycling Test (LER Motive and VAP Applications)

38.1 This test determines the electrical energy storage system's ability to withstand temperature fluctuations that may be anticipated during the end-use application. This test is only applicable to LER motive and VAP applications.

38.2 A fully charged battery system (MOSOC per 8.1) shall be placed in a test chamber and subjected to the following cycles in (a) – (e). At the conclusion of the cycling, the samples shall remain at room temperature, 25 ±5 °C (77 ±9 °F) for 24 h.

a) Raising the chamber-temperature to 75 ±2 °C (167 ±3.6 °F) within 30 min and maintaining this temperature for 6 h.

b) Reducing the chamber temperature to 20 ±2 °C (68 ±3.6 °F) within 30 min and maintaining this temperature for 2 h.

c) Reducing the chamber temperature to minus 40 ±2 °C (minus 40 ±3.6 °F) within 30 min and maintaining this temperature for 6 h.

d) Raising the chamber temperature to 20 ±2 °C (68 ±3.6 °F) within 30 min.

e) Repeating the sequence for a further 9 cycles.

*Exception No. 1: Temperatures may need to be held for longer periods for those larger systems where temperature stabilization may take longer. The time required in this case for systems that require longer exposures should be based upon the time it takes for the temperature on internal cells within the DUT to reach thermal equilibrium per 8.3 plus 1 additional hour. This time shall never be less than the exposure times noted in (a) – (d) above.*

*Exception No. 2: Testing may be conducted at a subassembly level if that is representative of the energy storage system.*

38.3 If the DUT is operational after the test, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.

38.4 During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

38.5 At the conclusion of the observation period, the sample is then subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

38.6 As a result of the thermal cycling test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 39 Resistance to Moisture Test

39.1 The purpose of this test is to determine that the battery system can safely withstand exposure to moisture anticipated in the end use.

39.2 With the DUT in its normal operating orientation, it shall be subjected to a moisture resistance test based upon its IP rating in accordance with IEC 60529 or CAN/CSA-C22.2 No. 60529. The battery system shall be installed and connected as intended for this test for the end use application. For batteries located where they may be subjected to flooding conditions, the IP rating will need to minimally cover immersion. If the DUT is operational after the conditioning, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications. An observation period per 8.5 is then conducted.

*Exception No. 1: Enclosures with Enclosure Type Ratings as identified in NFPA 70, Article 110, or Section 2 of C22.1, are subjected to the environmental testing outlined in UL 50E/C22.2 No. 94.2, rather than the IP Code.*

*Exception No. 2: Testing may be conducted at a subassembly level if that is representative of the energy storage system.*

39.3 During the test, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if venting of cells is anticipated. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the testing per Section 13.

39.4 At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

39.5 As a result of the resistance to moisture test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 40 Salt Fog Test

40.1 This test determines the electrical energy storage system's ability to safely withstand anticipated exposure to a salt fog conditions due to use near marine environments, and would apply to those stationary systems installed near sea environments whose internal components may be exposed to deterioration from salt fog through openings in the enclosure. This test would not apply to those systems not intended to be installed near marine environments as indicated in the installation instructions or whose enclosure is designed to prevent ingress of moisture with protection against corrosion (e.g. UL/NEMA 4X).

40.2 A fully charged electrical energy storage system (MOSOC per 8.1) shall be subjected to the test method per IEC 60068-2-52, with a severity level of 1 or 2 depending upon the application and location of installation.

*Exception: A sample at the subassembly level that would be representative of the battery system may be used for this test.*

40.3 If the DUT is operational after the conditioning, it shall be subjected to a discharge and charging cycle in accordance with the manufacturer's specifications.

40.4 During the cycling, one of the detection methods outlined in Section 9 shall be used to detect the presence of combustible vapor concentrations if venting of cells is anticipated. If required based upon system design or installation, venting of toxic releases shall be continuously monitored during the cycling per Section 13. An observation period per 8.5 is then conducted.

40.5 At the conclusion of the observation period, the DUT shall be subjected to an "as received" dielectric voltage withstand test in accordance with Section 22. The DUT shall be examined for signs of rupture and evidence of leakage.

40.6 As a result of the salt fog test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

## 41 External Fire Exposure for Projectile Hazards Test

41.1 The purpose of this test is to determine that a battery system will not explode as evidenced by projectiles landing beyond the test perimeter as a result of being exposed to a hydrocarbon pool fire simulating an external fire exposure that may occur.

*Exception No. 1: The battery system may be subjected to the External Fire Exposure Test in UL/ULC 2580 instead of the method outlined in 41.3.*

*Exception No. 2: Testing may be conducted on a representative subassembly rather than a complete battery system if determined that equivalent results to testing a battery system can be obtained.*

*Exception No. 3: If the secondary lithium cells employed in the system comply with the projectile test of Section E9, the system is exempted from this test. This test is not applicable to systems employing lead acid or similar monobloc aqueous electrolyte batteries.*

*Exception No. 4: This test does not apply to systems intended for outdoor use only that are mounted on a non-combustible surface such as a concrete pad that extends a minimum of 91.4 cm (3 ft) beyond the perimeter of the battery system.*

41.2 This test shall be conducted in a controlled setting free from the effects of wind or other environmental factors that may affect the test. The ambient temperature during the testing is to be within the range of 0 °C to 46 °C (32 °F to 114.8 °F).

41.3 A fully charged DUT at normal operating temperature is subjected to a hydrocarbon pool fire for 20 min. The fuel used shall be heptane or similar hydrocarbon fuel.

41.4 The pan, which provides the fire containment, shall be constructed of steel of sufficient thickness to prevent warping during the course of the 20-min test. The pan shall be sized in relation to the DUT and to accommodate the fuel and water levels. The walls of the pan shall not project more than 8 cm (3.1 in) above the level of the fuel at the start of the test. The pan dimensions shall be sized to ensure that the sides of the tested-device are exposed to the flame. The pan shall exceed the horizontal projection of the DUT by 20 to 50 cm (7.9 to 19.7 in).

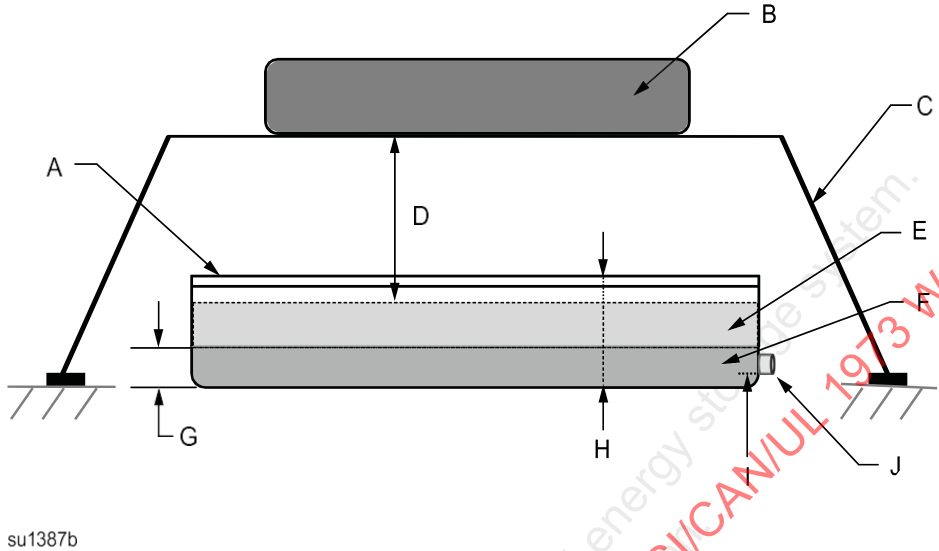
41.5 There should be approximately 15.24 cm (6 in) of water in the pan prior to adding the hydrocarbon fuel to protect the fuel pan and to provide for consistent flame output during the test. The fuel shall be added as needed during the test to provide sufficient fuel for the test duration. The fire shall cover the whole area of the pan during whole fire exposure.

41.6 A suitable means to extinguish the fire in the fuel pan within 15 s, or remove the battery from above the fire, shall be provided. This may be accomplished by drawing a cover over the pan, or by moving the DUT from over the pan or removing the pan as putting the fire out may be difficult and should not be underestimated.

41.7 The DUT shall be fully supported and centered above the fire containment pan above the surface of the heptane. The DUT support structure shall be robust enough to withstand the weight of the DUT for the duration of the test without allowing the DUT to lean or topple. The pan shall be sized large enough to cover the dimension of the DUT, and shall be of a sufficient height so that the bottom surface of the DUT is approximately 50 cm (19.7 in) from the top fuel surface in the pan. See Figure 41.1 for details of set up.

**Figure 41.1**

**Thermal Exposure for Explosion Hazards Test Set-Up**




A – Pan

B – DUT

C – Supporting Structure

D – 50 cm (19.7 in)

E – Fuel

F – Water

G – 15.24 cm (6 in)

H – 8 cm (3.1 in)

I - Fuel Port

J – Fuel supply port – centered on long side of pan



41.8 During the test, the temperature of the cells or modules within the DUT may be monitored for information purposes.

41.9 After the 20-min fire exposure the fire shall be extinguished, and the DUT shall be subjected to a hose down in accordance with 41.10 to represent fire fighter response the system may be exposed to during a fire. At the conclusion of the hose down, there shall be a one hour observation period in accordance with 8.5.

41.10 The battery shall be subjected to a low impact hose stream delivered through a 38 mm (1-1/2 in) fog nozzle set at a discharge angle of 30° with a nozzle pressure of 517 kPa (75 psi) and a minimum discharge of 4.7 L/s (75 gpm). The tip of the nozzle shall be a maximum of 1.5 m (5 ft) from the center of the exposed surface of the DUT. The minimum duration of the low impact hose stream test shall be 6.5 s/m$^2$ (0.60 s/ft$^2$). The outer surface of the DUT shall be identified as the exposed area, as the hose stream must traverse this area during its application. To prevent potential for exposure to projectiles, the technician conducting the hose down portion of the test shall do so behind a protective barrier.

41.11 To determine that an explosion hazard has resulted, the DUT with pan fire test set up shall be centered within a circular inner perimeter marked on the floor with paint or a similar marking material. The marking shall be no wider than 12 mm (0.47 in) and the size of the circular inner perimeter area marking shall be no greater than 1.0 m (3.3 ft) from the outer edge of the longest side of the DUT.

41.12 For protection from projectiles during the test, the DUT, test set up, and inner perimeter marking shall be enclosed within a protective test chamber that can contain the projectiles or within an outer perimeter consisting of a protective barrier wall of a noncombustible material such as masonry or concrete and wall thickness suitable for containing projectiles during the test. The walls of the test chamber or the outer perimeter shall be located a minimum of 1.5 m (4.95 ft) from the inner perimeter marking to prevent the possibility of projectiles bouncing off the walls and back into the inner perimeter.

41.13 As a result of this test, there shall be no explosion of the DUT that results in projectiles falling outside of the circular inner perimeter described in 41.11. See Table 12.1 for additional details.

## TOLERANCE TO INTERNAL CELL FAILURE TESTS

## 42 Single Cell Failure Design Tolerance

### 42.1 General

42.1.1 There have been field incidents with various battery technologies that have been attributed to a cell failure, which led to a hazardous event. The cell failures in these incidents were the result of either manufacturing defects or insufficient cell or battery design or a combination of both. Since there is a possibility that a cell may fail within a battery system, the battery system shall be designed to prevent a single cell failure from propagating to the extent that there is fire external to the DUT or an explosion.

42.1.2 The cell failure mechanism used for this testing shall reflect what is known or anticipated to occur in the field for a given technology. If the cell failure mechanism cannot be exactly replicated, a close simulation of what is known to occur in the field through the use of an external stress such as applied heating or mechanical force shall be utilized for the test. Examples of methods to simulate a single cell failure are outlined in Annex F. Multiple tests and possible multiple failure methods may need to be conducted as part of the analysis before a final methodology for testing is determined.

### 42.2 Single cell failure design tolerance (lithium ion)

42.2.1 A lithium ion battery system shall be designed to mitigate a single cell failure leading to a thermal runaway of that cell. With lithium ion batteries, it is often the effects of propagation to surrounding cells due to the heating effect of the initial cell failure that leads to hazardous events. The DUT (e.g. battery pack or module) shall be designed to prevent a single cell thermal runaway failure from creating a significant hazard as evidenced by fire propagation outside of the DUT and/or an explosion.

42.2.2 Any number of methods can be used to produce a single cell thermal runaway failure. For example, thermal runaway in cells can be achieved through the use of heaters, nail penetration, overcharge, etc. The testing agency is responsible for selecting and demonstrating an appropriate method for inducing thermal runaway. It is recommended to evaluate a candidate method first using a small subassembly of cells to evaluate the cell failure and effects to surrounding cells. During an effort to establish a suitable failure method, temperatures should be taken on the cell casings, and voltages measured for information purposes. See Annex F for guidance on several methods of inducing cell failure. The method chosen shall be agreed upon by the testing agency.

42.2.3 The details of the method used when analyzing the cell's reaction that can impact the results are to be documented. For example, if heating the cell to achieve failure: e.g. the type of heater and its dimensions, location on the cell where the heater is placed and how it is placed, maximum temperature attained including temperature ramp rate, length of time until reaction, temperatures on cell and voltage, state of charge of the cell at the beginning of the heating phase, etc. The test article shall be representative of the actual battery configuration and any modifications should not significantly impact the test results. For example, if overcharge is to be carried out, the heat conduction path between tabs shall not be hindered as that may reduce the severity of the test.

42.2.4 Once a suitable method of cell failure has been determined, the fully charged DUT (MOSOC per 8.1) shall be subjected to the single cell failure tolerance test, which consists of inducing a fault in one internal cell that is within the DUT, until cell failure resulting in thermal runaway as defined in 6.58 occurs, and determining whether or not that failure produces a significant external hazard or whether or not that failure does not cause the failure of neighboring cells. If cascading occurs, the cascading shall not propagate beyond the DUT. Prior to choosing the specific cell to fail, an analysis of the DUT design to determine the cell location considered to have the greatest potential to lead to a significant external hazard shall be conducted, taking into consideration the cell's proximity to other cells and materials that may lead to potential for propagation. If it can impact the results, the sample shall be at the maximum specified temperature during charging and operation with some tolerance as necessary for movement of the sample outside of the chamber during testing, but within ±10 °C (±18 °F) for cells just before inducing the mechanism to create thermal runaway. Once the thermal runaway is initiated, the mechanism used to create thermal runaway is shut off or stopped and the DUT is subjected to a 24-h observation period.

*Exception No. 1: Testing may be repeated on another sample with a cell in a different location within the DUT if it is not clear which location represents the worst case scenario. The location of the failed cell shall be documented for each test.*

*Exception No. 2: Testing may be conducted on a representative subassembly consisting of one or more modules and surrounding representative environment, if it can be demonstrated that there is no propagation beyond the subassembly. When testing at the module or subassembly level, consideration needs to be made of the vulnerability to combustion of those components surrounding the module in the final assembly. Temperatures on DUT external surfaces and surfaces of parts in contact with or near the DUT in the final assembly, shall be monitored to determine if excessive temperature on these adjacent parts could result in a potential for propagation within the full battery system. If there are excessive temperatures on the surfaces that may lead to potential for propagation, testing shall be repeated with all adjacent components in place of a complete battery system.*

42.2.5 Temperatures on the failed cell and surrounding cells, external enclosure surfaces of the DUT and the supporting surface are to be monitored and reported for information purposes.

42.2.6 As a result of the testing of 42.2, there shall be no fire propagating from the DUT or explosion of the DUT.

### 42.3 Single cell failure design tolerance (other technologies)

42.3.1 Other technologies such as lithium metal, sodium sulfur and sodium nickel chloride where there may not be enough field data regarding their tolerance to single cell failure events, are to be subjected to a single cell failure test method similar to 42.2, except as modified as noted below. The failure mechanism for these technologies may be different than that of lithium ion and thermal runaway may or may not result from the cell failure. Similar to lithium ion, when choosing a cell failure technique, it should be representative of what can occur in the field for the particular technology. The failure mechanism chosen shall consider failures due to potential cell manufacturing defects for that technology and/or cell and battery design deficiencies that could lead to latent failures of the cell, and that would not be evident under the individual cell safety testing.

42.3.2 For other technologies, similarly as with lithium ion, it is recommended to evaluate a candidate method first using a small subassembly of cells to evaluate the cell failure and effects to surrounding cells. During an effort to establish a suitable failure method, temperatures should be taken on the cell casings, and voltages measured for information purposes. See Annex F for guidance on several methods of inducing cell failure. The method chosen shall be agreed upon by the testing agency.

42.3.3 When a suitable worse case representative method for cell failure has been determined, the DUT is to be subjected to the internal cell failure occurring in the location within the DUT considered most vulnerable to the potential for propagation. The DUT shall be in a condition that reflects its operating parameters at the worst moment such a failure could occur. For example, the DUT shall be at its nominal operating temperature. During the test, temperatures shall be monitored in critical locations such as adjoining cells during the test to record the rise in temperature due to the internal failure. Temperatures on the external enclosure surfaces of the DUT and the supporting surface shall also be recorded for information purposes. If no thermal runaway occurs as a result of the single cell failure, the test is stopped when the DUT temperature has stabilized or reaches ambient room temperature, and the DUT is subjected to a 24-h observation period. If a thermal runaway is initiated, the mechanism used to create thermal runaway is shut off or stopped and the DUT is subjected to a 24-h observation period.

*Exception No. 1: Testing may be repeated on another sample with a cell in a different location within the DUT if it is not clear which location tested represented the worst case scenario. The location of the failed cell is to be documented for each test.*

*Exception No. 2: Testing may be conducted on a representative subassembly consisting of one or more modules and surrounding representative environment, if it can be demonstrated that there is no propagation beyond the subassembly. When testing at the module or subassembly level, consideration needs to be made of the vulnerability to combustion of those components surrounding the modules in the final assembly.*

42.3.4 As a result of the testing per 42.3.3, there shall be no fire propagating from the DUT or explosion of the DUT.

42.3.5 Temperatures on the failed cell and surrounding cells, external enclosure surfaces of the DUT and the supporting surface are to be monitored and reported for information purposes. The number of cells that fail due to propagation from the triggering cell shall be documented.

## MANUFACTURING AND PRODUCTION LINE TESTS

### 43 General

43.1 Manufacturers of battery systems shall have documented production process controls in place that continually monitor the following key elements of the manufacturing process that can affect safety, and shall include corrective/preventative action to address defects found affecting these key elements:

a) Supply chain control; and

b) Assembly processes.

43.2 Battery systems shall be subjected to 100 % production screening to determine that any active controls utilized for safety are functioning.

*Exception: This check of the safety controls can be conducted on subassemblies or components of the system before final assembly.*

43.3 An "as received" dielectric voltage withstand test as outlined in the Dielectric Voltage Withstand Test, Section 22 shall be conducted on 100 % production of Assemblies/packs with circuits exceeding 60 Vdc or 42.4 V peak as outlined in Section 22.

*Exception: The time for the test may be reduced to 1 s if the test voltage values are increase by 2.4 times the values in Section 22 or as outlined in the routine test criteria of the Electric Strength Test of UL 62368-1/CSA C22.2 No. 62368-1, Clause 5.4.9.*

43.4 A continuity check of the grounding system using a milliohmmeter or other method, shall be conducted on 100 % production employing protective grounding. The continuity check shall determine that measurements made on any two points of the grounding system do not exceed 0.1 Ω.

43.5 Each resettable non-ASME coded pressure-relief valve shall be tested by the manufacturer for the start-to-discharge pressure by subjecting the pressure-relief valve to a gradually increasing air pressure until the valve begins to open. The start-to-discharge pressure shall be in the range of 90 – 100 % of its rated start-to-discharge pressure rating.

## MARKINGS

### 44 General

*Advisory Note: In Canada, there are two official languages. Therefore, it is necessary to have CAUTION, WARNING, and DANGER instructions and markings in both English and French. Annex G lists acceptable French translations of the CAUTION, WARNING, and DANGER instructions and markings specified in this Standard. When a product is not intended for use in Canada, instructions and markings may be provided in English only.*

44.1 Required markings shall be permanent. Examples of permanent marking are ink stamping, engraving and if adhesive labels, compliance to UL 969 or CSA C22.2 No. 0.15 for the surface adhered and conditions of use. Markings required by this standard including nameplate markings per 44.2 and any cautionary markings shall be legible, provided in text color that contrasts with the background color and visible upon installation of the battery system.

44.2 Batteries shall be marked with the manufacturer's name, trade name, trademark or other descriptive marking which may identify the organization responsible for the product, part number or Model number, and electrical ratings in volts dc and capacity in Ampere-hours or Watt-hours and chemistry. The battery system terminals shall be marked to indicate whether they are positive (+) or negative (-). The battery shall also be marked with its IP rating.

44.3 Batteries and Battery systems using repurposed batteries in accordance with 7.13, shall be marked “Repurposed” or “Second Life” and “UL 1974”.

44.4 Battery systems shall be marked with the maximum short circuit current and duration (at maximum short circuit current) at the system output terminals.

44.5 Battery systems shall also be marked with the date of manufacture, which may be in the form of a code that does not repeat within 20 years.

44.6 A battery system intended for use with specific chargers shall be marked with the following or equivalent: "Use Only ( ) Charger".

44.7 A battery system evaluated for protection against ingress of moisture per 7.3.5, shall be provided with the appropriate IP Code rating.

44.8 Systems shall be marked with a cautionary marking indicating to read all instructions before installation, operation and maintenance of the system. This marking may be in the form of the symbol(s) for example: ISO 7000, "caution" Symbol No. 434 (exclamation point inside triangle) followed by the "read instruction manual" Symbol No. 790 (open book). If using symbols, their meaning shall be explained in the instruction manual.

44.9 Systems that must be operated in a certain orientation for safe operation, shall be provided with markings indicating the correction orientation of the system.

44.10 Systems shall be marked with a warning marking indicating risk of electrocution near hazardous voltage battery terminals.

44.11 Systems with replaceable fuses, shall be marked with rating and type of fuse for replacement. The marking shall be located near the fuseholder.

44.12 Separable accessories and controls which are intended for connection to the mains supply shall be provided with markings that include the manufacturer's name, part number of the accessory and electrical ratings in voltage, frequency, phase if applicable, and current or watts.

44.13 A ground terminal shall be marked as outlined in 7.6.8.

44.14 Additional warning markings for battery systems located in restricted access locations such as warnings regarding hazardous moving or electrical parts, hot surfaces, etc., to alert service or other trained personnel and prevent hazards, shall be provided on the battery systems in locations where they will be visible those persons having access to the location.

44.15 With reference to 7.12.2, a secondary lithium cell shall be legibly and permanently marked with:

a) The manufacturer's name, trade name, or trademark or other descriptive marking by which the organization responsible for the product may be identified;

b) A distinctive catalog, model or designation number or the equivalent; and

c) The date or other dating period of manufacture not exceeding any three consecutive months.

*Exception No. 1: The manufacturer's identification may be in a traceable code if the product is identified by the brand or trademark owned by a private labeler.*

*Exception No. 2: The date of manufacture may be abbreviated; or may be in a nationally accepted conventional code or in a code affirmed by the manufacturer, provided that the code:*

*a) Does not repeat in less than 10 years; and*

*b) Does not require reference to the production records of the manufacturer to determine when the product was manufactured.*

44.16 With reference to 44.15, if a manufacturer produces a cell at more than one factory, each cell shall have a distinctive marking to identify it as the product of a particular factory.

44.17 Required markings for single cells and multi-cell/monobloc vented and valve regulated lead acid and nickel cadmium batteries shall be legibly and permanently marked in accordance with 44.1 with the following included:

a) The manufacturer's name, trade name or trademark, model designation, and month and year of manufacture;

*Exception: The date of manufacture may be in the form of a code that does not repeat in 10 years.*

b) The statement "Warning: Risk of fire, explosion, or burns. Do not disassemble, heat above XX °C (or °F), or incinerate." (Where XX is the cell or battery's maximum temperature specification.)

*Exception: This statement may be included in the instructions provided with the cell or battery, rather than be marked on the battery.*

c) Battery type (e.g. valve regulated lead-acid battery) and rated nominal voltage and capacity; and

d) Positive and negative leads or terminals indicated by (+) and (−).

## INSTRUCTIONS

### 45 General

45.1 Components of a battery system shall be provided with a complete set of instructions for proper installation and use in a battery system. These instructions shall include normal operating specifications.

45.2 Systems shall be provided with complete instructions for installation in the end use application. Installation instructions shall include the following along with any other instructions necessary for the safe and correct installation of the system and its accessories in the intended end use:

a) Insulated tools, insulated gloves, personal protective equipment, and clothing and other measures necessary for safe installation of the battery system;

b) The necessary housing requirements for protection against ingress of moisture and debris or access by persons;

c) Ventilation requirements to prevent accumulation of hydrogen greater than 25 % of hydrogen LFL;

d) Protective components and devices required in the end use installation such as fuses, circuit breakers, wiring, and other devices such as disconnect devices in accordance with NFPA 70 or C22.1. See 7.9.9;

e) Circuit diagrams and instructions for proper connection of the system and any ancillary devices such as separate controllers, monitoring devices, etc.;

f) Warnings and instructions regarding the battery electrolyte;

g) Instructions regarding any commissioning tests and checks necessary before placing system into service;

h) Table or list, etc. of symbols used and their meanings;

i) The necessary information to complete an arc flash/blast analysis, including bolted fault current (IBF), 1/2 bolted fault current (1/2 IBF), protective device clearing time, and protective device current interrupt capability at a minimum, if applicable to the system; and

j) If applicable, the manufacturer shall provide information on design considerations for maximum and minimum system configurations, such as number of modules installed in series, maximum resistance, and maximum inductance to prevent arc flash incident energy from exceeding the requirements of Personal Protective Equipment Category 4 per NFPA 70E or CSA Z462-15.

45.3 Battery systems intended for installation in a restricted access location per 6.51 shall have installation instructions indicating this with instructions defining the type of location required, its restrictions, signage and other information to be provided.

45.4 A system shall be provided with instructions for the proper use including charging and discharging, storage, recycling and disposal. These instructions shall include temperature limits, charging and discharging limits as well as instructions regarding the use of any controls or monitoring systems.

45.5 A system shall include the following statements or equivalent:

a) An attention word, such as "DANGER," "WARNING," or "CAUTION."

b) A brief description of possible hazards.

c) A list of actions to take to avoid possible hazards regarding disposal of the system such as do not crush, disassemble, dispose of in fire, or similar actions.

45.6 The system shall be provided with a maintenance manual that includes a schedule for maintenance of the system and accessories including a check of wiring and connections, etc. The maintenance manual shall include necessary safety precautions regarding handling or conducting maintenance on the system and its connections and accessories.

45.7 Cells shall be provided with a complete set of instructions that include operating region specifications for charging and discharging including current temperature range and voltages, installation instructions, storage of batteries and disposal instructions. Guidance on cell specification information that should be provided on cells can be found in the Cell Specification Sheet, Annex E of IEEE 1625.

45.8 The installation instructions for vented and valve regulated lead acid and nickel cadmium batteries shall indicate that the batteries and components of the battery systems shall be installed in accordance with Article 480 or 706 of NFPA 70 or Section 64 of CSA C22.1.

45.9 Installation instructions for vented and valve regulated lead acid and nickel cadmium batteries shall indicate that the charging system for these batteries shall prevent charging outside of the battery specifications through the use of voltage (and temperature for VRLA) monitoring and controls, or both current and temperature monitoring and controls. The system may also use current monitoring to prevent out of condition specifications. The instructions shall indicate that chargers shall comply with UL 1012, UL 1741, UL 60335-2-29/CSA C22.2 No. 60335-2-29, CAN/CSA C22.2 No. 107.2, or UL 62368-1/CSA C22.2 No. 62368-1. Instructions for the battery system shall provide information on a specific charger to be used with the battery system if the charger is relied upon to maintain the battery system safety.

45.10 The instructions for vented and valve regulated lead acid and nickel cadmium batteries shall indicate that battery systems exceeding 60 Vdc shall be provided with a disconnecting means for all ungrounded conductors in accordance with Article 480 of NFPA 70 or Section 64 of CSA C22.1.

45.11 Installation instructions for single cells and multi-cell/monobloc vented and valve regulated lead acid and nickel cadmium batteries shall be provided with instructions indicating that service disconnects shall be provided as applicable to the end product battery system in accordance with Article 480 of NFPA 70 or Section 64 of CSA C22.1.

45.12 Installation instructions for vented and valve regulated lead acid and nickel cadmium multi-battery/cell systems shall include the short circuit current output from the battery system rather than the marking of 44.4.

45.13 Vented lead acid or nickel cadmium cell and battery installation instructions shall indicate the need for spill control in accordance with the building, fire and installation codes.

45.14 The instructions for vented and valve regulated lead acid and nickel cadmium cells and batteries shall indicate that ventilation to address any hydrogen off gassing shall be in accordance with the local fire and installation codes.

45.15 The instructions for open rack vented and valve regulated lead acid and nickel cadmium battery systems shall indicate that these racks shall be installed in restricted access locations or be installed within a protective enclosure that prevents access in accordance with the end use application.

45.16 Instructions for vented and valve regulated lead acid and nickel cadmium cells and batteries shall indicate recommended wiring for battery connections, the minimum clearance between cells and batteries on the racks and any type of protection device.

45.17 Instructions for vented and valve regulated lead acid and nickel cadmium cells and batteries shall include maintenance instructions for maintaining the cells and batteries in safe operating condition through the life of the cell and battery including electrolyte maintenance if applicable, examination of terminals and casings for damage, etc.

45.18 If lead acid and nickel cadmium cells and batteries are intended for installation in an end use that utilizes protective grounding, the installation instructions shall recommend that the grounding and bonding system be checked after the completion of the assembly to ensure that the resistance is less than or equal to 0.1 Ω.

45.19 The instructions provided with lead acid and nickel cadmium cells and batteries shall indicate the maximum voltage of the end use system they can be installed in. If the voltage in the end use is exceeded, then the instructions shall recommend a repeat of the dielectric voltage withstand test of the assembly for the higher voltage.

## Annex A (Normative)

### A1 Standards for Components

A1.1 The CSA Group and UL standards listed below are used for evaluation of components and features of products covered by this standard. Components shall comply with all the applicable CSA Group and UL component standards. These standards shall be considered to refer to the latest edition and all revisions published to that edition.

**CSA Group Standards**

C22.2 No. 14, *Industrial Control Equipment*

C22.2 No. 49, *Flexible Cords and Cables*

C22.2 No. 65, *Wire Connectors*

C22.2 No. 75, *Wires and Cables, Thermoplastic-Insulated*

C22.2 No. 127, *Equipment and Lead Wires*

C22.2 No. 153, *Electrical Quick-Connect Terminals*

C22.2 No. 158, *Terminal Blocks*

C22.2 No. 182.1, *Plugs, Receptacles, and Cable Connectors, of the Pin and Sleeve Type*

C22.2 No. 182.3, *Special Use Attachment Plugs, Receptacles and Connectors*

C22.2 No. 235, *Supplementary Protectors*

C22.2 No. 248.1, *Fuses, Low Voltage – Part 1: General Requirements*

CAN/CSA-C22.2 No. 60947-4-1, *Low-Voltage Switchgear and Controlgear – Part 4-1: Contactors and Motor-Starters – Electromechanical Contactors and Motor-Starters*

CAN/CSA-E61131-2, *Programmable Controllers – Part 2: Equipment Requirements and Tests*

**UL Standards**

UL 44, *Thermoset-Insulated Wires and Cables*

UL 62, *Flexible Cords and Cables*

UL 66, *Fixture Wire*

UL 83, *Wires and Cables, Thermoplastic-Insulated*

UL 98B, *Enclosed and Dead-Front Switches for Use in Photovoltaic Systems*

UL 248-1 (and all applicable parts), *Low-Voltage Fuses – Part 1: General Requirements*

UL 248-13, *Low-Voltage Fuses – Part 13: Semiconductor Fuses*

UL 252, *Compressed Gas Regulators*

UL 310, *Terminals, Electrical Quick-Connect*

UL 429, *Electrically Operated Valves*

UL 444, *Communications Cables*

UL 467, *Grounding and Bonding Equipment*

UL 486A-486B, *Wire Connectors*

UL 489, *Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures*

UL 489F, *Molded-Case Circuit Breakers and Molded-Case Switches for Use with Battery Power Supplies*

UL 489G, *Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures, 650 – 1000 Volts AC and 650 – 1500 Volts DC*

UL 498, *Attachment Plugs and Receptacles*

UL 499, *Electric Heating Appliances*

UL 508, *Industrial Control Equipment*

UL 508A, *Industrial Control Panels*

UL 514A, *Metallic Outlet Boxes*

UL 796, *Printed-Wiring Boards*

UL 796F, *Flexible Materials Interconnect Constructions*

UL 857, *Busways*

UL 991, *Tests for Safety-Related Controls Employing Solid-State Devices*

UL 1004-1, *Rotating Electrical Machines – General Requirements*

UL 1053, *Ground-Fault Sensing and Relaying Equipment*

UL 1059, *Terminal Blocks*

UL 1063, *Wires and Cables, Machine-Tool*

UL 1077, *Supplementary Protectors for Use in Electrical Equipment*

UL 1434, *Thermistor-Type Devices*

UL 1441, *Coated Electrical Sleeving*

UL 1577, *Optical Isolators*

UL 1581, *Reference Standard for Electrical Wires, Cables, and Flexible Cords*

UL 1598, *Luminaires*

UL 1653, *Electrical Nonmetallic Tubing*

UL 1682, *Plugs, Receptacles, and Cable Connectors, of the Pin and Sleeve Type*

UL 1861, *Power-Operated Chemical Pumps*

UL 1977, *Connectors for Use in Data Signal and Power*

UL 2238, *Cable Assemblies and Fittings for Industrial Control and Signal Distribution*

UL 2419, *Electrically Conductive Corrosion Resistant Compounds*

UL 2591, *Battery Cell Separators*

UL 2726, *Battery Lead Wire*

UL 2734, *Connectors and Service Plugs for Use with On-Board Electrical Vehicle (EV) Charging Systems*

UL 4127, *Low Voltage Battery Cable*

UL 4128, *Intercell and Intertier Connectors for Use in Electrochemical Battery System Applications*

UL 4248-1, *Fuseholders – Part 1: General Requirements*

UL 9703, *Distributed Generation Wiring Harnesses*

UL 60691, *Thermal-Links – Requirements and Application Guide*

UL 60730-2-6, *Automatic Electrical Controls for Household and Similar Use – Part 2: Particular Requirements for Automatic Electrical Pressure Sensing Controls Including Mechanical Requirements*

UL 60730-2-9, *Automatic Electrical Controls for Household and Similar Use – Part 2-9: Particular Requirements for Temperature Sensing Controls*

UL 60947-1, *Low-Voltage Switchgear and Controlgear – Part 1: General Rules*

UL 60947-4-1, *Low-Voltage Switchgear and Controlgear – Part 4-1: Contactors and Motor-Starters – Electromechanical Contactors and Motor-Starters*

UL 60947-5-2, *Low-Voltage Switchgear and Controlgear – Part 5-2: Control Circuit Devices and Switching Elements – Proximity Switches*

UL 61058-1, *Switches for Appliances – Part 1: General Requirements*

UL 61131-2, *Programmable Controllers – Part 2: Equipment Requirements and Tests*

## Annex B (Normative)

## Test program for sodium-beta battery cells

### B1 General

B1.1 Battery systems that employ sodium-beta cells and batteries shall comply with the applicable construction and test requirements outlined in this standard. They shall additionally be subjected to the requirements of this Annex.

B1.2 Table B.1 outlines the tests and sample number of cells for the tests of this Annex. Refer to Table 8.1 for the sample numbers of batteries used in battery tests.

**Table B.1**
**Cell Samples for Tests**

| Test | Section | Number of fresh cells | Number of cycled cells |
|---|---|---|---|
| **Electrical** | | | |
| Cell short circuit | B2.1.1 | 2 | 2 |
| Cell abnormal charging | B2.1.2 | 2 | 2 |
| **Mechanical** | | | |
| Cell shock[a] | B2.2.1 | 1 | |
| Cell vibration | B2.2.2 | 1 | |
| **Environmental** | | | |
| Cell heating | B2.3.1 | 2 | 2 |
| Cell temperature cycling | B2.3.2 | 1 | |
| [a] A small battery module may be used. | | | |

### B2 Cell Tests

### B2.1 Electrical

#### B2.1.1 Cell short circuit

B2.1.1.1 Two as received fully charged cells and two fully charged cells previously subjected to charge/discharge cycling outlined in B2.1.1.2 shall comply with the short circuit test of B2.1.1.3.

B2.1.1.2 The cycled cells shall be cycled continuously in accordance with the manufacturer's specifications. The specifications shall be such that the full capacity of the cell is utilized and the number of cycles accumulated shall be at least equal to 25 % of the advertised cycle life of the cell or cycled continuously for 90 days, whichever is shorter. Cycling shall be done either individually or in groups. The cell is then recharged prior to testing.

B2.1.1.3 Each test sample shall be short-circuited by connecting the positive and negative terminals to a resistance load of less than or equal to 20 mΩ. The testing is conducted at room ambient 25 ±5 °C (77 ±9 °F) with the cell heated to its normal operating temperature. Testing is continued until the cell is fully discharged and the temperature returns to operating ambient. The test is repeated with the short circuit condition applied first and then the cell heated to its normal operating temperature.

B2.1.1.4 As a result of the short circuit, the cell shall not explode or catch fire.

### B2.1.2 Cell abnormal charging

B2.1.2.1 Two as received fully charged cells and two fully charged cells previously subjected to charge/discharge cycling outlined in B2.1.1.2 shall comply with the abnormal charging test of B2.1.2.2 – B2.1.2.4.

B2.1.2.2 Cells shall be discharged to the manufacturer's specified end of discharge conditions. Each test sample, at its specified operating temperature, shall be subjected to a constant current charging at the specified maximum charging current Ic until the maximum (abnormal) charging voltage as specified by the manufacturer is reached. Then the charging is continued using constant voltage charging at the maximum (abnormal) charging voltage for 7 h.

B2.1.2.3 When an overcurrent device operates during the test, the test is repeated on samples with a charging inputs below the trip point of the protective device.

B2.1.2.4 As a result of the abnormal charging, there shall be no fire or explosion.

## B2.2 Mechanical

### B2.2.1 Cell shock test

B2.2.1.1 A fresh sample of cell or fully charged small battery module (per MOSOC of 8.1) shall comply with the shock test as outlined below.

B2.2.1.2 The sample shall be secured to the testing machine by means of a rigid mount, which supports all mounting surfaces of the sample. Each sample shall be subjected to a total of three shocks of equal magnitude. The shocks shall be applied in each of three mutually perpendicular directions for a total of 18 shocks unless the sample has only two axes of symmetry, in which case only two directions are tested for a total of 9. The parameters of the shock applied are as noted in the Table B.2 below. The shocks shall be applied with the sample at room temperature of 25 °C ±5 °C (77 °F ±9 °F). At the conclusion of the shock testing the sample is operated (i.e. charged/discharged) at its normal operating temperature for 1 cycle to determine if it has been made hazardous as a result of the shock conditioning.

**Table B.2**
**Shock Testing Parameters**

| Sample type | Waveform type | Peak acceleration | Pulse duration, ms |
|---|---|---|---|
| Cell | Half sine | 150 g | 6 |
| Small battery module | Half sine | 50 g | 11 |

B2.2.1.3 The samples shall not explode or catch fire. The maximum mass percent loss of the cell shall be 0.1 %. For sodium sulfur type cells, the cell casing temperature shall be equal or less than that of a fresh cell when cycled.

### B2.2.2 Cell vibration

B2.2.2.1 One fresh sample of the cell shall be subjected to simple harmonic motion with an amplitude of 0.8 mm (1.6 mm total maximum excursion).

B2.2.2.2 The frequency shall be varied at a rate of 1 Hz/min between 10 and 55 Hz, and return in not less than 90 min or more than 100 min. The cell is tested in three mutually perpendicular directions unless it has only two axes of symmetry, in which case it is only to be tested perpendicular to each axis. The vibration conditioning shall be at an ambient of 25 ±5 °C (77 ±9 °F). At the conclusion of the testing, the cell shall be operated (i.e. charged/discharged) for 1 cycle at it normal operating temperature to determine if it is hazardous after being subjected to the vibration conditioning.

B2.2.2.3 The cells shall not explode or catch fire. The maximum mass percent loss of the cell shall be 0.1 %. For sodium sulfur type cells, the cell casing temperature shall be equal or less than that of a fresh cell when cycled.

**B2.3 Environmental**

**B2.3.1 Cell heating**

B2.3.1.1 Two fresh cells and two cells previously subjected to the charge discharge cycling of B2.1.1.2 were subjected to the cell heating test of B2.3.1.2.

B2.3.1.2 The cells shall be placed in an air circulating oven or gravity convection oven. The temperature shall be raised from an ambient of 25 ±5 °C (77 ±9 °F) at a rate of 5 ±2 °C/min (7.5 ±3.6 °F/min) to a temperature of 25 ±2 °C (77 ±3.6 °F) above the maximum operating temperature of the cell and held for 30 min. The test is then discontinued.

B2.3.1.3 As a result of the heating, there shall be no fire or explosion.

**B2.3.2 Cell temperature cycling**

B2.3.2.1 One fresh cell shall be subject to the temperature cycling test of B2.3.2.2.

B2.3.2.2 The sample shall be placed in a test chamber and subjected to the following cycles:

a) Raising the chamber temperature to 85 ±2 °C (185 ±3.6 °F) within 30 min and maintaining this temperature for 4 h.

b) Reducing the chamber temperature to 20 ±2 °C (68 ±3.6 °F) within 30 min and maintaining this temperature for 2 h.

c) Reducing the chamber temperature to minus 40 ±2 °C (minus 40 ±3.6 °F) within 30 min and maintaining this temperature for 4 h.

d) Raising the chamber temperature to 20 ±2 °C (68 ±3.6 °F) within 30 min.

e) Repeating the sequence for 9 additional cycles for a total of 10 cycles.

B2.3.2.3 After the tenth cycle the cell shall be operated (i.e. charged/discharged) for one cycle at its normal operating temperature.

B2.3.2.4 The cell shall not explode or catch fire. The maximum percent mass loss of the cell shall be 0.1 %. For sodium sulfur type cells, the cell casing temperature shall be equal or less than that of a fresh cell when cycled.

## Annex C (Normative)

## Test program for flowing electrolyte batteries

### C1 General

C1.1 Battery systems consisting of flowing electrolyte batteries shall comply with the applicable construction and test requirements of this standard. They shall additionally be subjected to the requirements outlined in this Annex.

*Exception: The Overdischarge Protection Test, Imbalanced Charging Test, and Drop Impact Test are not conducted on flowing electrolyte systems.*

C1.2 The sample criteria for the cell stack tests is outlined in Table C1.1.

**Table C1.1**
**Cell Stack Samples for Tests**

| Test | Section | Number of cell stacks tested |
|---|---|---|
| Vibration of cell stack | C4.1 | 1 |
| Shock test on cell stack (drop impact exception) | C4.2 | 1 |
| High temperature test on cell stack | C4.3 | 1 |
| Short circuit test on cell stack | C4.4 | 1 |

### C2 Materials Containing Electrolyte – Resistance to Deterioration from Fluids

C2.1 Parts containing electrolyte shall be resistant to deteriorations from the fluids they contain. Compliance is determined by the testing outlined in C2.2 and C2.3. As a result of the testing, the tensile strength of tested materials shall not be less than 80 % of the tensile strength of the material in the as received condition.

C2.2 Three as-received samples of materials conditioned as described in C2.3 shall be tested in accordance with ASTM D638. Prior to tensile strength testing, the samples shall be conditioned at a standard lab temperature of 23 °C (73.4 °F), 50 % humidity for 40 h. The tensile strength of the materials under test shall be recorded.

C2.3 Nine samples shall be immersed in the test liquid representative of the electrolyte contained. Three samples shall be conditioned for 7 days, three for 30 days and three for 60 days at a temperature of 50 °C (122 °F) in a full-draft air-circulating explosion-proof oven. Following the exposure tests the samples shall be removed from the oven and from the test liquid then conditioned at a standard lab temperature of 23 °C (73.4 °F), 50 % humidity for 40 h prior to tensile testing. Samples are evaluated from each of the exposure times for tensile strength and compared with as-received samples. The 60 day exposure test may be waived depending upon the results of samples subjected to the 30 day exposure.

C2.4 Gaskets and seals which contain the electrolyte shall be subjected to the volume change and extraction, tensile strength and elongation after 70 h immersion in the electrolyte at a temperature of 50 °C (122 °F) in accordance with UL 157. Prior to mechanical testing, the samples shall be cooled by use of a container of the electrolyte at 23 °C (73.4 °F) for 30 min. The tensile strength and elongation shall be a minimum of 60 % of the as received values and the volume change of minus 1 to +25 % of the as received values and extraction (change in weight) no greater than 10 %.

## C3 Materials Containing Electrolyte – Temperature Exposure

C3.1 Parts containing electrolyte shall be suitable for intended temperature use. Compliance is determined by the testing of C3.2 and C3.3. As a result of the oven aging, the part shall not show signs of deterioration such as cracking or embrittlement. The tensile strength of the conditioned part shall not be less than 80 % of the tensile strength of the as received part.

C3.2 Three as-received samples of materials conditioned as described in C3.3 shall be tested in accordance with ASTM D638. Prior to tensile strength testing, the samples shall be conditioned at a standard lab temperature of 23 °C (73.4 °F), 50 % humidity for 40 h. The tensile strength of the materials under test shall be recorded.

C3.3 Six samples of materials shall be conditioned in a full-draft air-circulating oven, three for 45 days and three for 90 days at a temperature of 70 °C (158 °F). Following the oven conditioning the samples shall be removed from the oven and then conditioned at a standard lab temperature of 23 °C (73.4 °F), 50 % humidity for 40 h prior to tensile testing. The samples are evaluated from each of the conditioning times for tensile strength and compared with as-received samples.

*Exception No. 1: As an alternative test method, the part shall be conditioned for 30 and 60 days at a temperature of 80 °C (176 °F) in a full-draft air-circulating oven.*

*Exception No. 2: As an alternative test method, the parts shall be conditioned for 15 and 30 days at a temperature of 90 °C (194 °F) in a full-draft air-circulating oven.*

C3.4 Gaskets and seals which contain the electrolyte shall be subjected to the air oven aging test of UL 157. The test temperature shall be in accordance with Table 4.3 of UL 157 and based upon the anticipated exposure temperatures in the end use application. Following oven conditioning, the samples shall be conditioned at a standard lab temperature of 23 °C (73.4 °F), 50 % humidity for 16 h prior to tensile and elongation testing. The tensile strength and elongation after oven aging shall be a minimum of 60 % of the as received values.

C3.5 Gasket and seals used in electrolyte containment systems shall be subjected to the lower temperature test of UL 157 for minus 40 °C (minus 40 °F), or the lowest ambient temperature specified by the manufacturer, but not higher than 0 °C (32 °F), with no visible evidence of cracking in accordance with the test criteria of UL 157.

## C4 Flowing Electrolyte Cell Stack Tests

### C4.1 Vibration of cell stack

C4.1.1 One sample of a flowing electrolyte cell stack shall be subjected to vibration in accordance with C4.1.2 and C4.1.3. As a result of the vibration conditioning, the cell stack shall not be damaged to the extent that results in leaks. See Table C1.1.

C4.1.2 The DUT shall mounted to a vibration text fixture and subjected to a simple harmonic motion with an amplitude of 0.76 mm, and a total maximum excursion of 1.52 mm. The frequency is varied at the rate of 1 Hz/min between the limits of 10 Hz and 55 Hz. The entire range of frequencies (10 Hz to 55 Hz) and return (55 Hz to 10 Hz), is traversed in 90 ±5 min for each mounting position (direction of vibration). The vibration is applied in each of three mutually perpendicular directions.

*Exception: Another method of vibration representative of the transport conditions of the cell stack such as ISO 13355, or IEC 60068-2-64, etc. may be used if determined to be more suitable for the size and design of the stack.*

C4.1.3 At the conclusion of the vibration conditioning, the DUT shall be checked for leaks by subjecting it to the leakage test C5.2.

### C4.2 Shock test on cell stack

C4.2.1 One sample of a flowing electrolyte cell stack shall be subjected to the shock test in accordance with C4.2.2 and C4.2.3. As a result of the shock conditioning, the cell stack shall not be damaged to the extent that results in leaks. See Table C1.1.

C4.2.2 The DUT shall be secured to a test machine by means of a rigid mounts supporting all surfaces of the cell stack. Each DUT shall be subjected to a total of three shocks of equal magnitude. The shocks shall be applied in each of three mutually perpendicular directions. For each shock the DUT shall be accelerated in such a manner that during the initial 3 ms, the minimum average acceleration is 75 g (where g is the local acceleration due to gravity). The peak acceleration shall be between 125 and 175 g.

*Exception: Where it is not practical to conduct a shock test on the DUT due to its size or configuration, it may be subjected to a drop impact test in accordance with Section 31 instead.*

C4.2.3 At the conclusion of the shock conditioning or impact test, the DUT shall be checked for leaks by subjecting it to the leakage test C5.2.

### C4.3 High temperature test on cell stack

C4.3.1 One sample of the flowing electrolyte cell stack shall be subjected to the high temperature test in accordance with C4.3.2 and C4.3.3. As a result of the high temperature conditioning, the cell stack shall not be damaged to the extent that results in leaks. See Table C1.1.

C4.3.2 The DUT shall be conditioned for 7 h in an air circulating temperature chamber at a temperature of 10 ±2 °C (50 ±3.6 °F) plus the maximum temperature rating of the cell stack or 70 ±2 °C (158 ±3.6 °F), whichever is greater.

C4.3.3 At the conclusion of the high temperature conditioning, the DUT shall be allowed to cool to room ambient and then it shall be checked for leaks by subjecting it to the leakage test of C5.2.

### C4.4 Short circuit test on cell stack

C4.4.1 A cell stack shall be subjected to a short circuit test to a total external resistance of less than or equal to 20 mΩ until the cell stack is completely discharged, or the operation of an integral protective device or other results. See Table C1.1.

C4.4.2 As a result of the short circuit test, there shall be no fire or explosion.

## C5 Flowing Electrolyte Battery System Tests

### C5.1 Hydraulic pressure test

C5.1.1 Electrolyte containment vessels where there is the potential for gas pressure build up having a pressure-times-volume value greater than 200 kPa-L (7.67 psi-gal), and pressure greater than 50 kPa (7.25 psi), shall be subjected to a hydraulic pressure test as described in C5.1.2. As a result of the test, the vessel shall not burst, leak, rupture, fracture, or permanently (plastic) deform.

*Exception No. 1: Where unmarked pressure vessels are not able to be hydraulically tested, compliance shall be verified by other applicable tests, such as an air pneumatic test at the same test pressure as for the hydraulic test.*

*Exception No. 2: Piping systems under the scope of ASME B31.3, shall be subjected to ultimate strength and leakage testing in accordance with that code.*

C5.1.2 The test pressure shall be the maximum pressure specified by the manufacturer multiplied by five or 1.5 times the operating pressure of a pressure relief device, whichever is greater. A pressure-relief device which is used to limit the maximum pressure shall be inactive during the test. The pressure shall be raised gradually to the specified test value and held at that value for 1 min.

### C5.2 Leakage test

C5.2.1 Leakage from fluid-containing parts shall not result in the risk of fire, electric shock, or injury to persons. As a result of the leakage test, the following in (a) – (h) are considered non-compliant results:

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

C5.2.2 Compliance is determined by subjecting the parts to a fluid pressure of 1.5 times the maximum pressure (if testing with liquid) or 1.1 times the maximum pressure (if air pneumatic testing) of intended use during operation of the system. There shall be no leaks as a result.

### C5.3 Electrolyte blockage tests

#### C5.3.1 Pump failure/blockage during charging

C5.3.1.1 A pump failure or potential electrolyte blockage from another cause during charging may lead to an overcharge condition in a flowing electrolyte battery system.

C5.3.1.2 The Overcharge test of Section 15 shall additionally consider, for flowing electrolyte type battery systems, an overcharge condition that can result from an electrolyte pump failure or other cause leading to electrolyte line blockage.

#### C5.3.2 Pump failure/blockage during discharging

C5.3.2.1 A pump failure or potential electrolyte blockage from another cause during discharge may lead to an overdischarge condition in an flowing electrolyte battery system.

C5.3.2.2 A test shall be conducted to evaluate any hazards resulting from an electrolyte pump failure or electrolyte blockage during a maximum constant current discharge.

C5.3.2.3 As a result of the pump failure/blockage during discharging test, the following in (a) – (h) are considered non-compliant results. For additional information on non-complying results refer to Table 12.1.

a) E – Explosion;

b) F – Fire;

c) C – Combustible vapor concentrations;

d) V – Toxic vapor release;

e) S – Electric shock hazard (dielectric breakdown);

f) L – Leakage (external to enclosure of DUT);

g) R – Rupture (of DUT enclosure exposing hazardous parts as determined by 7.3.3);

h) P – Loss of protection controls.

### C5.4 Short circuit test

C5.4.1 When conducting the short circuit test of Section 17 on the system, the electrolyte flow rate shall be maintained at a constant rate during the test, until the protection operates, the system is discharged or other ultimate results occur to end the test.

### C5.5 Insulation resistance

C5.5.1 Systems shall have sufficient insulation resistance to prevent hazards associated with energized electrolyte fluids traveling through the system.

C5.5.2 The resistance of insulation used on hazardous voltage circuits within the flowing electrolyte battery shall be greater than or equal to 1 MΩ when conducting the test of C5.5.3.

C5.5.3 The insulation resistance shall be measured using high impedance measuring equipment (e.g. mega ohmmeter) after applying a voltage of 500 Vdc between the live parts of the circuit under test and accessible conducting parts including the equipment grounding circuit, for 1 min.

*Exception: The insulation resistance test of IEC 60364-6, Low voltage electrical installations – Part 6: Verification, can be conducted instead. Compliance criteria is in accordance with the IEC 60364-6 when using this method.*

### C5.6 Failure of the cooling/thermal stability system test

C5.6.1 When conducting the failure of the cooling/thermal stability system test of Section 24, the battery system shall be tested at ambient temperature rather than tested in a test chamber.

## C6 Spill Containment Systems

C6.1 If spill containment systems such as containment vessels and/or absorption pillows are used for containment, absorption or neutralization of electrolyte spills from a flowing electrolyte battery, the materials and parts of the system shall be subjected to the applicable tests of UL 2436.

*Exception: Tests involving exposure to or use of electrolyte other than sulfuric acid shall be modified from those of UL 2436 based upon the electrolyte, utilized in the flowing electrolyte system under test.*

## Annex D (Normative)

## Metal compatibility

### D1 General

D1.1 For combinations that fall above the line in Table D.1, an evaluation on the parts can be conducted to determine suitability. Protection methods such as coatings can be used, but will need to be evaluated.

D1.2 The evaluation method shall consist of a comparison of the part to evaluate with a similar part using construction that is below the line of Table D.1, after corrosion conditioning such as a salt fog conditioning in accordance with ASTM B117, ISO 9227 or similar method. Measurements of the properties of the connection parts (design under consideration as well as comparison design) under test shall be made before and after conditioning with a comparison of the results. Properties to measure will depend upon the part being evaluated, but could include resistance, temperatures on the part during operation, or bond/mechanical strength as applicable to the type of connection.

D1.3 The deterioration of the devices under evaluation shall not result in unacceptable properties (i.e. reduced performance that would result in malfunction of the connection) nor shall the deterioration be greater than that of the comparison design.

D1.4 As another approach, a coating with known properties, such as one evaluated to UL 546, along with sealing the area to prevent moisture exposure can be used to establish acceptable protection against galvanic corrosion without additional evaluation.

## Table D.1

## Metal Compatibility Table

| Magnesium, magnesium alloys | Zinc, zinc alloys | 80 tin/20 Zn on steel, Zn on iron or steel | Aluminium | Cd on steel | Al/Mg alloy | Mild steel | Duralumin | Lead | Cr on steel, soft solder | Cr on Ni on steel, tin on steel, 12% Cr stainless steel | High Cr stainless steel | Copper, copper alloys | Silver solder, austenitic stainless steel | Ni on steel | Silver | Rh on Ag on Cu, silver/gold alloy | Carbon | Gold, platinum | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.5 | 0.55 | 0.7 | 0.8 | 0.85 | 0.9 | 1.0 | 1.05 | 1.1 | 1.15 | 1.25 | 1.35 | 1.4 | 1.45 | 1.6 | 1.65 | 1.7 | 1.75 | Magnesium, magnesium alloys |
| | 0 | 0.05 | 0.2 | 0.3 | 0.35 | 0.4 | 0.5 | 0.55 | 0.6 | 0.65 | 0.75 | 0.85 | 0.9 | 0.95 | 1.1 | 1.15 | 1.2 | 1.25 | Zinc, zinc alloys |
| | | 0 | 0.15 | 0.25 | 0.3 | 0.35 | 0.45 | 0.5 | 0.55 | 0.6 | 0.7 | 0.8 | 0.85 | 0.9 | 1.05 | 1.1 | 1.15 | 1.2 | 80 tin/20 Zn on steel, Zn on iron or steel |
| | | | 0 | 0.1 | 0.15 | 0.2 | 0.3 | 0.35 | 0.4 | 0.45 | 0.55 | 0.65 | 0.7 | 0.75 | 0.9 | 0.95 | 1.0 | 1.05 | Aluminium |
| | | | | 0 | 0.05 | 0.1 | 0.2 | 0.25 | 0.3 | 0.35 | 0.45 | 0.55 | 0.6 | 0.65 | 0.8 | 0.85 | 0.9 | 0.95 | Cd on steel |
| | | | | | 0 | 0.05 | 0.15 | 0.2 | 0.25 | 0.3 | 0.4 | 0.5 | 0.55 | 0.6 | 0.75 | 0.8 | 0.85 | 0.9 | Al/Mg alloy |
| | | | | | | 0 | 0.1 | 0.15 | 0.2 | 0.25 | 0.35 | 0.45 | 0.5 | 0.55 | 0.7 | 0.75 | 0.8 | 0.85 | Mild steel |
| | | | | | | | 0 | 0.05 | 0.1 | 0.15 | 0.25 | 0.35 | 0.4 | 0.45 | 0.6 | 0.65 | 0.7 | 0.75 | Duralumin |
| | | | | | | | | 0 | 0.05 | 0.1 | 0.2 | 0.3 | 0.35 | 0.4 | 0.55 | 0.6 | 0.66 | 0.7 | Lead |
| | | | | | | | | | 0 | 0.05 | 0.15 | 0.25 | 0.3 | 0.35 | 0.5 | 0.55 | 0.6 | 0.65 | Cr on steel, soft solder |
| | | | | | | | | | | 0 | 0.1 | 0.2 | 0.25 | 0.3 | 0.45 | 0.5 | 0.55 | 0.6 | Cr on Ni on steel, tin on steel, 12% Cr stainless steel |
| | | | | | | | | | | | 0 | 0.1 | 0.15 | 0.2 | 0.35 | 0.4 | 0.45 | 0.5 | High Cr stainless steel |
| | | | | | | | | | | | | 0 | 0.05 | 0.1 | 0.25 | 0.3 | 0.35 | 0.4 | Copper, copper alloys |
| | | | | | | | | | | | | | 0 | 0.05 | 0.2 | 0.25 | 0.3 | 0.35 | Silver solder, austenitic stainless steel |
| | | | | | | | | | | | | | | 0 | 0.15 | 0.2 | 0.25 | 0.3 | Ni on steel |
| | | | | | | | | | | | | | | | 0 | 0.05 | 0.1 | 0.15 | Silver |
| | | | | | | | | | | | | | | | | 0 | 0.05 | 0.1 | Rh on Ag on Cu, silver/gold alloy |
| | | | | | | | | | | | | | | | | | 0 | 0.05 | Carbon |
| | | | | | | | | | | | | | | | | | | 0 | Gold, platinum |

su0803c

Ag = Silver
Al = Aluminium
Cd = Cadmium
Cr = Chromium
Cu = Copper
Mg = Magnesium
Ni = Nickel
Rh = Rhodium
Zn = Zinc

Note – Corrosion due to electrochemical action between dissimilar metals which are in contact is minimized if the combined electrochemical potential is below about 0.6 V. In the above table the combined electrochemical potentials are listed for a number of pairs of metals in common use; combinations above the dividing line should be avoided.

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# Annex E (Normative)

# Cell Test Program

## E1 General

E1.1 The following shall be used to evaluate lithium ion cells or other secondary lithium cells.

E1.2 Samples used for testing shall be representative of production. The number of samples used for each test and the pass/fail criteria for testing is outlined in Table E.1. As an alternate, the lithium ion cell test program outlined in Sections E10 – E11 may be used.

E1.3 Prior to conditioning in E1.4, two samples from the total set of samples as representative samples shall be subjected to the capacity check per E2.2 to confirm the capacity of the samples is correct.

E1.4 Prior to testing, the samples shall be conditioned by first discharging them down to the manufacturer’s specified end point voltage and then charging them to the manufacturer's specified upper limit charging voltage using the manufacturer's specified maximum charging current. Samples shall be charged at the upper temperature limit of the charging operating region and the lower limit of the charging operating region for those tests as identified in Table E.1. During charging, a minimum of one temperature is measured on the surface of the cell centered on the cell. For prismatic cells, this would be on the largest flat surface.

**Table E.1**
**Test Samples and Results Criteria**

| Test | Section | Number of samples conditioned at upper limit temperature per E1.4[a] | Number of samples conditioned at lower limit temperature per E1.4[a] | Total samples tested | Compliance[c] |
|---|---|---|---|---|---|
| Short Circuit | E3 | 1 | 1 | 2 | No: fire or explosion |
| Cell Impact | E4 | 1 | 1 | 2 | No: fire or explosion |
| Drop Impact | E5 | – | – | 2 | No: fire or explosion |
| Heating | E6 | 1 | 1 | 2 | No: fire or explosion |
| Overcharge | E7 | 1 | 1 | 2 | No: fire or explosion |
| Forced Discharge | E8 | – | – | 2 | No: fire or explosion |
| Projectile | E9 | – | – | 2 (4) | No: projectiles in accordance with E9.2. |

[a] The upper limit temperature, lower limit temperature, upper limit charging voltage, maximum charging current, discharge current and end point voltage parameters used for conditioning of cell samples are specified by the cell manufacturer.

[b] Those cells not complying with the Projectile Test of E9 can be used in batteries that comply with the Thermal Exposure for Explosion Hazards Test of Section 41.

[c] Test results for compliance criteria is defined in E12.2.

E1.5 Some lithium cells are capable of exploding when the tests described in this Annex are conducted. It is important that personnel be protected from the flying fragments, explosive force, sudden release of heat, and noise that results from such explosions. The test area shall be well ventilated to protect personnel from possible harmful fumes or gases.

E1.6 As an additional precaution, the temperatures on the surface of the cell casings shall be monitored in accordance with E1.7 during the tests described in this Annex. All personnel involved in the testing of lithium cells shall be instructed never to approach a lithium cell while the surface temperature exceeds 90 °C (194 °F) and not to touch the lithium cell while the surface temperature exceeds 45 °C (113 °F).

E1.7 In accordance with E1.6, the surface temperatures of the cell casing shall be measured as follows:

a) By thermocouples consisting of wires not larger than 0.21 $mm^2$ (24 AWG) and not smaller than 0.05 $mm^2$ (30 AWG) and a potentiometer-type instrument; and

b) The temperature measurements on the cells shall be made with the measuring junction of the thermocouple held tightly against the metal casing of the cell.

*Exception: Placing the thermocouple on a thin piece of paper or label is an acceptable practice.*

E1.8 For protection, the Projectile Test in E9 shall be conducted in a room separate from the observer or within an appropriate containment chamber.

**E2 Preconditioning and Capacity Check**

**E2.1 Preconditioning**

E2.1.1 The charge/discharge cycling preconditioning in E2.1.2 shall be done before testing and conducted on secondary lithium metal (i.e. lithium metal anode) cells. Lithium ion cells need not be subjected to charge/discharge cycle preconditioning.

E2.1.2 Secondary lithium metal (i.e. lithium metal anode) cells shall be conditioned at 25 °C ±5 °C (77 °F ±9 °F). The cells shall be continuously cycled as specified by the manufacturer. The specification shall be such that the full rated capacity of the cell is utilized and the number of cycles accumulated shall be at least equal to 25 % of the advertised cycle life of the cell or cycled continuously for 90 days, whichever is shorter. Cycling shall be done either individually or in groups. Cells shall be recharged prior to testing.

**E2.2 Capacity check**

E2.2.1 Prior to conducting testing, the capacity of the lithium ion and lithium metal cells to be tested shall be checked in accordance with E2.2.2 – E2.2.5 by selecting two samples from the total set of samples.

E2.2.2 For secondary lithium metal (i.e. lithium metal anode) cells, this capacity check shall be conducted on preconditioned secondary lithium metal cells per E2.1.

*Exception : For secondary lithium metal cells subjected to preconditioning per E2.1, the capacity check may be conducted during the preconditioning of these secondary lithium metal cells by checking the discharged capacity during the first few cycles. This capacity confirmation may be done in the manufacturer shipping inspection by checking the capacity discharge curve shipped with the samples.*

E2.2.3 The cell shall be discharged at 25 °C ±5 °C (77 °F ±9 °F) at a constant current of 0.2C rate, down to a specified end of discharge voltage. The cell shall then be charged in a room ambient temperature, 25 °C ±5 °C (77 °F ±9 °F), at charging parameters specified by the manufacturer until fully charged. The cell shall then be allowed to stabilize at room ambient per 6.52.

E2.2.4 With the cell in the fully charged condition, the cell shall be discharged at a constant current discharge in accordance with the cell manufacturer's specifications down to the end of discharge voltage. The duration of the discharge shall be monitored and the measured capacity of the cell shall be calculated to three significant figures.

E2.2.5 For cells to be used for the test program outlined in this Annex, their measured capacity shall equal or exceed the rated specifications. All samples shall be subjected to the capacity check test if any representative sample does not meet this criteria. The cells not meeting this criteria shall be excluded from testing.

## E3 Short Circuit

E3.1 Fully charged, conditioned cells are stored in an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F) until their casing reaches ambient temperature, and then subjected to a short circuit condition using an external resistance of ≤ 20 mΩ.

E3.2 The external resistance shall be applied to the cell terminals for 7 h or until temperatures on the cell cool to within ±10 °C (18 °F) of ambient conditions.

E3.3 The sample and compliance criteria shall be in accordance with Table E.1.

## E4 Cell Impact

E4.1 Fully charged, conditioned cells shall be subjected to an impact test as outlined in E11.4. The cells shall be at an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F) prior to testing.

E4.2 The sample and compliance criteria shall be in accordance with Table E.1.

## E5 Drop Impact

E5.1 Fully charged cells shall be dropped three times from a height of 1 m (3.3 ft) onto a flat concrete or metal surface. The cells shall be at an ambient temperature of 25 °C ±5 °C (77 °F ±9 °F) prior to testing.

E5.2 The cells shall be dropped in a manner that the impacts occur in random orientations.

E5.3 After completion of the impacts, the cells shall be subjected to a minimum one hour observation period before being examined.

E5.4 The sample and compliance criteria shall be in accordance with Table E.1.

## E6 Heating

E6.1 Fully charged, conditioned cells shall be subjected to a heating test as outlined in E11.7.

E6.2 The sample and compliance criteria shall be in accordance with Table E.1.

## E7 Overcharge

E7.1 Fully charged conditioned cells shall be discharged in accordance to manufacturer's specifications down to the specified end point voltage. The test is conducted in an ambient of 25 °C ±5 °C (77 °F ±9 °F) and with the cell casing at an ambient of 25 °C ±5 °C (77 °F ±9 °F) at the start of the test. The voltage and temperature of the cell shall be monitored during the test.

E7.2 The cells are charged with a constant current at the maximum specified charge current until the voltage of the cell reaches 120 % of the maximum specified charge voltage value or 130 % State of Charge (SOC), whichever is reached first. The charge is then terminated while the cell temperature continues to be monitored. The test is concluded when the cell temperature drops and returns to ±10 °C (18 °F) of the test ambient.

E7.3 The sample and compliance criteria shall be in accordance with Table E.1.

## E8 Forced Discharge

E8.1 Fully charged cells shall be discharged in accordance to manufacturer's specifications down to the specified end point voltage. The test is conducted in an ambient of 25 °C ±5 °C (77 °F ±9 °F).

E8.2 The discharged cells are subjected to a forced discharge at a constant current 1.0 $I_t$ A for 90 min with the discharge voltage limit not to exceed the numerical value of the upper limit charging voltage specified for the cell. If the discharge voltage limit is reached before the 90 min, the cell shall be discharged at a constant voltage discharge equal to the manufacturer's determined low voltage cutoff, with the current decreasing as necessary until the 90 min time period is reached.

E8.3 The sample and compliance criteria shall be in accordance with Table E.1.

## E9 Projectile

E9.1 Two fully charged cells shall be subjected to the projectile test criteria as outlined in E11.10.

E9.2 As a result of the projectile test, the cells there shall not be an explosion of the cells resulting in projectiles with sufficient force to penetrate the test cage screen.

## ALTERNATIVE TEST PROGRAM FOR SECONDARY LITHIUM CELLS

## E10 General

E10.1 This cell test program may be used to evaluate secondary lithium cells for use in battery systems that comply with this standard instead of the test program outlined in Sections E1 – E9. Samples used for testing shall be representative of production. The number of samples used for each test and the pass/fail criteria for testing shall be as outlined in Table E.2.

E10.2 Some lithium cells are capable of exploding when the tests described below are conducted. It is important that personnel be protected from the flying fragments, explosive force, sudden release of heat, and noise that results from such explosions. The test area shall be well ventilated to protect personnel from possible harmful fumes or gases.

E10.3 As an additional precaution, the temperatures on the surface of the cell casings shall be monitored in accordance with E10.4 during the tests described below. All personnel involved in the testing of lithium cells shall be instructed never to approach a lithium cell while the surface temperature exceeds 90 °C (194 °F) and not to touch the lithium cell while the surface temperature exceeds 45 °C (113 °F).

E10.4 In accordance with E10.3, the surface temperatures of the cell casing shall be measured as follows:

a) By thermocouples consisting of wires not larger than 0.21 $mm^2$ (24 AWG) and not smaller than 0.05 $mm^2$ (30 AWG) and a potentiometer-type instrument; and

b) With the measuring junction of the thermocouple held tightly against the metal casing of the cell.

*Exception: Placing the thermocouple on a thin piece of paper or label is an acceptable practice.*

E10.5 For protection, the Projectile Test in E11.10 shall be conducted in a room separate from the observer or within an appropriate containment chamber.

E10.6 Secondary lithium metal (i.e. lithium metal anode) cells shall be conditioned in accordance with E2.1 prior to the testing.

E10.7 The capacity of the samples for all lithium chemistries shall be confirmed in accordance with E2.2 prior to testing.

## E11 Tests

### E11.1 Short-circuit test

E11.1.1 Each test cell shall be short-circuited by connecting the positive and negative terminals with a resistance load of less than or equal to 20 mΩ. The temperature of the cell case shall be recorded during the test. The short circuit shall be applied until the cell case temperature has returned to ±10 °C (±18 °F) of ambient temperature.

E11.1.2 Tests shall be conducted at 55 ±5 °C (131 ±9 °F). The samples shall reach equilibrium at 55 ±5 °C (131 ±9 °F), as applicable, before the terminals are connected.

E11.1.3 The sample and compliance criteria shall be as noted in Table E.2.

### E11.2 Overcharge test

E11.2.1 The cell shall be subjected to the overcharge test as outlined in E11.2.2.

E11.2.2 A cell shall be subjected to a constant current charge at the maximum specified charging current until the cell reaches 120 % of its maximum specified charge voltage limit or it reaches 130 % SOC, whichever comes first.

E11.2.3 The sample and compliance criteria shall be in accordance with Table E.2.

### E11.3 Crush test

E11.3.1 A cell shall be subjected to a bar crush using a bar with a 15-cm (5.9-in) diameter. The force for the crushing shall be applied by a hydraulic ram or similar force mechanism. The force shall be applied until one of the following in (a) – (c) occurs. Once the maximum force has been obtained, the force shall be released.

a) A voltage (OCV) drop of one-third of the original cell voltage occurs;

b) A deformation of 15 % or more (in the direction of the crush) of initial cell dimension occurs; or

c) A force of 1000 times the weight of cell is reached.

E11.3.2 A cylindrical, pouch or prismatic cell shall be crushed with its longitudinal axis parallel to the crushing apparatus. Each sample shall be subjected to a crushing force in only one direction and the crush shall be conducted only on the wide side of a pouch or prismatic cell. Separate samples shall be used for each test. See also, E11.3.3 and E11.3.4.

E11.3.3 With reference to E11.3.2, for other than pouch cells, the crush shall be applied in the center of the cells.

E11.3.4 With reference to E11.3.2, for pouch type cells, the crushing force shall be applied on the casing near where the cell tabs exit. If the positive and negative tabs are on opposite sides, the crush force shall be applied on the casing near where the negative tab exits.

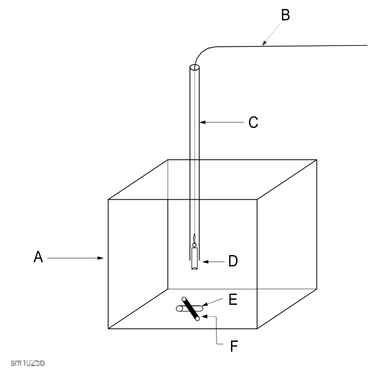
E11.3.5 sample and compliance criteria shall be in accordance with Table E.2.

### E11.4 Impact test

E11.4.1 A cell shall be placed on a flat surface. A 15.8 ±0.1-mm (5/8 ±0.004-in) diameter bar shall be placed across the center of the sample. A 9.1 ±0.46-kg (20 ±1-lb) weight shall be dropped from a height of 610 ±25 mm (24 ±1 in) onto the sample. See Figure E.1.

**Figure E.1**

**Impact test**




A – Steel impact chamber (hinged door not shown)

B – Weight support rope

C – Containment tube

D – 9 kg (20 lb) weight

E – Cell

F – 16-mm (5/8-in) diameter bar



E11.4.2 The cell shall be impacted with its longitudinal axis parallel to the flat surface and perpendicular to the longitudinal axis of the 15.8-mm (5/8-in) diameter curved surface lying across the center of the test sample. For prismatic and pouch cells, only the wide side shall be impacted. Each sample shall be subjected to only a single impact. Separate samples shall be used for each test.

E11.4.3 The sample and compliance criteria shall be in accordance with Table E.2.

### E11.5 Shock test

E11.5.1 The cell shall be secured to the testing machine by means of a rigid mount which supports all mounting surfaces of the cell. Each cell shall be subjected to a total of three shocks of equal magnitude. The shocks shall be applied in each of three mutually perpendicular directions unless it has only two axes of symmetry in which case only two directions shall be tested. Each shock shall be applied in a direction normal to the face of the cell.

E11.5.2 For each shock, the cell shall be accelerated in such a manner that during the initial 3 ms the minimum average acceleration is 75 g (where g is the local acceleration due to gravity). The peak acceleration shall be between 125 and 175 g. Cells shall be tested at a temperature of 25 ±5 °C (77 ±9 °F).

E11.5.3 The sample and compliance criteria shall be in accordance with Table E.2.

### E11.6 Vibration test

E11.6.1 A cell shall be subjected to simple harmonic motion with an amplitude of 0.8 mm (0.03 in) [1.6 mm (0.06 in) total maximum excursion].

E11.6.2 The frequency shall be varied at the rate of 1 Hz/min between 10 and 55 Hz, and return in not less than 90 nor more than 100 min. The cell shall be tested in three mutually perpendicular directions. For a cell that has only two axes of symmetry, the cell shall be tested perpendicular to each axis.

E11.6.3 At the end of the vibration conditioning, the open circuit voltage (OCV) of the cell is measured and compared with the pre-test value.