



IEEE Standard for Rechargeable Batteries for Multi-Cell Mobile Computing Devices

IEEE Power & Energy Society

Sponsored by the
Stationary Batteries Committee

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IEEE Standard for Rechargeable Batteries for Multi-Cell Mobile Computing Devices

Sponsor

**Stationary Batteries Committee
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IEEE Power & Energy Society**

Approved 26 September 2008

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Abstract: Guidance for the designer/manufacturer/supplier in planning and implementing controls for the design and manufacture of lithium-ion and lithium-ion polymer rechargeable battery packs used for mobile computing devices is provided. The provisions of this standard work together, and they define approaches to design, test, and evaluate a cell, battery pack, and host device to mitigate battery system failure in end-user environments. Additionally, recommendations for end-user education and communication materials are provided in this standard. This approach suggests the interfaces between subsystems (for example, cell, battery pack, host device) and end users are as important to system reliability as is robust subsystem design and testing. Therefore, subsystem interface design responsibilities for each subsystem designer/manufacturer/supplier are provided, as well as messaging and communication provisions for end-user awareness. The influence of the end user in system reliability is also recognized in this standard.

Keywords: battery, battery pack, cell, host device, lithium-ion (Li-ion), lithium-ion polymer (Li-ion polymer), mobile computing device, pack, portable computing, rechargeable battery, rechargeable battery packs

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Introduction

This introduction is not part of IEEE Std 1625-2008, IEEE Standard for Rechargeable Batteries for Multi-Cell Mobile Computing Devices.

The Portable Computer Battery Working Group was created to provide a platform based on the experience of industry leaders in cell, battery pack, and systems management leading to design approaches for mobile computing devices, such as notebook computers. This standard focuses on design approaches for the reliable operation of mobile computing devices and similar rechargeable battery-operated systems with multiple cells in series or series and parallel. Third-party certification is out of the scope of this standard. This standard may be relevant to other devices, but these devices were not expressly considered in the development of this standard.

Users of mobile computing devices with only one or more cells in parallel (but none in series) are directed to IEEE Std 1725™-2006 [B18]^a for possible applicability.

Figure a presents the need for an approach involving all subsystems of the system, including the end user and environment, to arrive at a satisfactory end-user experience. It is necessary to examine all design margins in combination to understand the true effect of a multiple-fault response on the mobile computing device. The standard addresses the following questions:

- What are the critical operational parameters?
- How do these parameters change with time and environment?
- What are the effects of extremes in temperature, pressure, and impact?

A total system view is required to protect the design margins in the various components. The goal of reliability and positive end-user experience requires that design margins be maintained as end-user patterns, profiles, and duty cycles change.

This standard applies to all types of rechargeable lithium-ion (Li-ion) and lithium-ion polymer (Li-ion polymer) batteries and battery packs with multiple series cells or series and parallel for use in mobile computing devices. The intent of this standard is to consider the interaction of the technologies manufactured by cell manufacturers, battery pack assemblers, and systems integrators. Because of the nature of the interactions between the battery and the host device, a system approach shall be used in developing an appropriate operating envelope for the system. The provisions of this standard are intended to provide considerations for design analyses to minimize the occurrence of failures leading to hazards. For devices that have multiple functions, manufacturers may choose the primary function of the device to determine which standard applies.

This standard is a system-level standard as depicted in Figure a. Overall compliance is dependent on conformity to each and every subclause of this standard. Compliance with the standard cannot be achieved by any particular multi-cell mobile computing device or subsystem alone without considering the conformity of all subsystems within the system as well as the end user. It is incumbent upon the manufacturers/suppliers of the host device, battery pack, and cell to thoroughly review their designs, alone and in conjunction with other subsystems, to identify faults that could propagate hazards. Once it has been ascertained that the cell, battery pack, and host device conform to all of their particular subclause requirements, the overall system compliance is not complete until the manufacturer/supplier completes a thorough design analysis, for example, design failure mode and effects analysis, to ensure their particular design minimizes the risk of hazards that may occur during intended use and reasonably foreseeable misuse. Additionally, the recommended end-user education and communication should be followed.

^a The numbers in brackets correspond to those of the bibliography in Annex G.

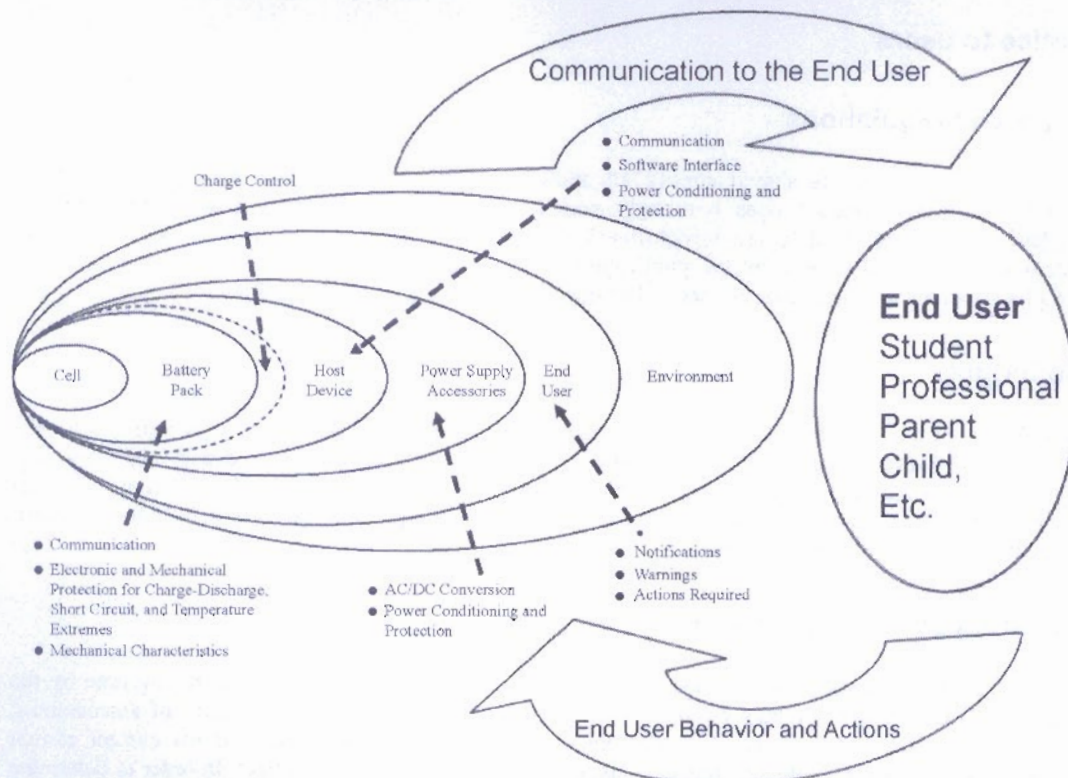


Figure a—Conceptual diagram of a mobile computing device and its end user.
Examples of functions for each subsystem component are shown

This standard includes seven annexes—one normative annex, which is required for compliance with this standard, and six informative annexes, which are not required for compliance with this standard. Annex A (informative) briefly describes failure mode effects and analysis techniques. Annex B (informative) provides guidance about a two-fault tolerant system analysis. Annex C (informative) reports environmental considerations encountered in automobiles. Annex D (informative) provides information about test methodologies to evaluate a battery cell's ability to withstand internal shorts due to manufacturing, design, or external abuse. The only normative annex contained herein, Annex E, includes a template for describing battery cell characteristics. The template in Annex E identifies those characteristics that shall be communicated on a Cell specification sheet. Annex F (informative) is a glossary of definitions that this standard uses that are not unique to this standard; however, they are provided for better understanding of this standard. Annex G (informative) contains bibliographic references.

Disclaimer

Compliance with the provisions of this standard does not imply compliance to the regulatory requirements that are applicable to cell, battery packs, and systems. Care must be used to observe and refer to the applicable regulatory requirements, as part of the intended design analyses, for this standard does not assure protection or safety. This standard sets forth recommendations for design analyses and certain testing procedures. The level of protection and safety resulting from applying this standard depends on the implementation by the manufacturer/supplier and the actions of the end user. Compliance with this standard does not guarantee safety in all circumstances.

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Battery Association of Japan	Intel	Sony Corporation
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Battery Association of Japan	International Business Machines	Sony Corporation
Dell Inc.	Motorola, Inc.	Texas Instruments, Inc.
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1. Overview

This standard guides manufacturers/suppliers in planning and implementing the controls for the design and manufacture of lithium-ion (Li-ion) and lithium-ion polymer (Li-ion polymer) rechargeable battery packs used for multi-cell mobile computing devices.

The provisions of this standard work together to define approaches to design, test, and evaluate a cell, battery pack, and host device to mitigate battery system failure. Additionally, this standard provides recommendations for end-user education and communication materials. This approach recommends the interfaces between subsystems (for example, cell, battery pack, host device, power adapter, etc.), and end users are as important to system reliability as is robust subsystem design and testing. This standard, therefore, includes subsystem interface design responsibilities for each subsystem manufacturer/supplier, and it provides messaging and communication provisions for end-user awareness. Therefore, the responsibility for total system reliability is shared between the designers/manufacturers/suppliers of the subsystems and the end user. Compliance to this standard requires adherence to all the provisions of the standard.

CAUTION

This standard, and its accompanying annexes, provides no guarantee of protection or safety for battery end users. This standard sets forth recommendations for design analyses and certain testing procedures. The level of protection and safety resulting from applying this standard depends on the implementation by the manufacturer/supplier and the actions of the end user. In the recommendations for design analyses contained herein, this standard contemplates intended use and reasonably foreseeable misuse by the end user. However, compliance with this standard does not provide a complete guarantee against hazards to the end user, such as fire, explosion, and leakage.

1.1 Scope

This standard establishes criteria for design analysis for qualification, quality, and reliability of rechargeable battery systems for multi-cell mobile computing devices. It also provides methods for quantifying the operational performance of these batteries and their associated management and control systems including considerations for end-user notification. This standard covers rechargeable battery systems for mobile computing. The battery technologies covered are limited to Li-ion and Li-ion polymer, but future versions of this standard may include technologies that are not in general use at present. Also included are: battery pack electrical and mechanical construction; system, pack, and cell level charge and discharge controls; and battery status communications. The following are addressed: qualification process; manufacturing process control; energy capacity and demand management; levels of management and control in the battery systems; current and planned lithium-based battery chemistries, packaging technologies, and considerations for end-user notification.

2. Normative references

The following referenced documents are indispensable for the application of this document (that is, they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

WARNING

Some of the tests specified herein can be dangerous to the persons carrying them out. All appropriate measures to protect personnel against possible chemical, thermal, and/or explosion hazards should be taken.

AIAG SPC-3, Statistical Process Quality Control, Second Edition, 2005.¹

ANSI/ASQ 9002, Quality Management Systems Requirements.²

IEC 60695-11-10, Fire hazard testing—Part 11-10: Test flames—50 W horizontal and vertical flame test methods.³

IEC 60950-1:2005, Information technology equipment—Safety—Part 1: General requirements.

IEC 62133:2002, Secondary cells and batteries containing alkaline or other non-acid electrolytes—Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications.

IEC 62281, Safety of primary and secondary lithium cells and batteries during transport.

IPC-A-610, Acceptability of Electronic Assemblies.⁴

IPC-2221, Generic Standard on Printed Board Design.

¹ AIAG publications are available from the Automotive Industry Action Group, 26200 Lahser Rd., Suite 200, Southfield, MI 48033-7100, USA (<http://www.aiag.org>).

² ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

³ IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

⁴ IPC publications are available from the Institute for Interconnecting and Packaging Electronic Circuits (IPC), 2215 Sanders Road, Northbrook, IL 60062-6135, USA (<http://www.ipc.org/>).

ISO 9001, Quality management systems—Requirements.⁵

UL 94, Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances.⁶

UL 1642-2005, Standard for Lithium Batteries.

UL 2054, Standard for Household and Commercial Batteries.

UL 60950-1, Information Technology Equipment—Safety—Part 1: General Requirements.

UN ST/SG/AC.10/11/Rev.4-2003, Recommendations on the Transport of Dangerous Goods—Manual of Tests and Criteria, Fourth Revised Edition.⁷

3. Definitions

For the purpose of this standard, the following terms and definitions apply. The glossary in Annex F and *The Authoritative Dictionary of IEEE Standards Terms* [B17] should be referenced for terms not defined in this clause.⁸

3.1 abuse: Use of product in a way that is not intended by the manufacturer/supplier but which may result from unreasonable or malicious human behavior or unreasonably extreme conditions or environments.

3.2 active authentication: A method of qualification of a battery and/or accessory where the system makes the compatibility decision independent from the end user. For example, the use of a secure memory device within the battery pack that communicates to the host that the pack is suitable for use with a specific OEM's mobile computing device.

3.3 active charger: A charger that has a communication channel and interacts with the host device.

3.4 adapter: A device that transforms the available power from an external source (for example, ac wall outlet, airline, or automobile outlets, etc.) to the power used by the host.

3.5 aging of cells: Manufacturing process(es) from initial charge to final acceptance.

3.6 authentication: Any method of qualification of a battery and/or accessory designed to ensure compatibility with a specific host device.

3.7 battery/battery pack: An assembly of any number of Li-ion or Li-ion polymer cells, associated electronics, battery packaging, and connector(s).

3.8 battery management circuit: An integrated circuit that manages battery operation to prevent overvoltage, overcurrent, and stops battery operation at set high and low temperatures as well as at a set low-voltage cutoff.

3.9 burr: A sharp metallic projection at the edge of an electrode foil that may penetrate the separator and cause an internal short in a Li-ion or Li-ion polymer cell.

NOTE—See Figure 6.⁹

⁵ ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iso.ch/>). ISO publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

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⁸ The numbers in brackets correspond to those of the bibliography in Annex G.

3.10 cell: Basic manufactured Li-ion or Li-ion polymer unit providing a source of electrical energy by direct conversion of chemical energy that consists of electrodes, separators, electrolyte, container, and terminals, and that is designed to be charged electrically.

3.11 cell block: One or more cells connected in parallel.

3.12 cell core: Internal cell assembly consisting of positive and negative electrodes integrated with separator. Electrodes and separator may be spirally wound ("jelly roll") or stacked ("cut and stack") in a planar arrangement.

3.13 cell production lot: A group of cells that have similar characteristics as a result of common materials, manufacturing timeframe, or other identifiable characteristics according to the manufacturer's specifications.

3.14 charge and discharge test current (I_t): $I_t A = C_n Ah / 1h$, where C_n is the rated capacity declared by the cell manufacturer in ampere hours (Ah) and 'n' is the time base in hours (h) for which the rated capacity is declared.

3.15 charge control: The specific mechanism that supervises/controls the charge of a battery.

3.16 charger: A charger is a device that imposes a voltage and current in the proper polarity on a cell or battery to return the battery to a higher state of charge (SOC).

3.17 charging algorithm: The set of rules and decisions used to determine the voltages and currents applied to the cell, cells, and/or battery pack as a function of time, temperature, or other parameters.

3.18 critical: (A) Of, relating to, or being a turning point or an especially important juncture. (B) Relating to or being a state in which, or a measurement or point at which, some quality, property, or phenomenon suffers a definite change.¹⁰

3.19 critical change: Any change that would increase the chance of a hazard.

3.20 design analysis: The evaluation of a design to determine correctness with respect to stated requirements, conformance to design standards, system efficiency, and other criteria, including consideration of system aging and usage over the life of the product.

3.21 fault: A defect in the cell/host/pack that causes the device to fail to perform normally.

3.22 fresh cells: Cells as received from the vendor prior to any additional assembly or use of those cells.

3.23 host (host device): The device that is powered by a battery and/or charges the battery. Mobile computing devices and external chargers are examples of a host device.

3.24 incompatible batteries: Battery products that do not meet the proper mechanical and/or electrical requirements for safe and reliable operation of the host device.

3.25 intended use: Use of a product in accordance with specifications, instructions, and information provided by the manufacturer/supplier.

⁹ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

¹⁰ Critical limits, critical steps, traceability plans, etc., may be considered to be critical design factors. Such parameters are determined by the manufacturer/supplier.

3.26 manufacturer/supplier: An entity that designs and/or assembles and/or markets finished mobile computing devices or cells, battery packs, and/or systems, as appropriate.

3.27 overcharge: The forcing of a current through a battery pack after it has been fully recharged. Overcharge may damage the normal operation of the cell or battery and/or induce a hazard.

3.28 overcurrent: The situation where the current to or from a cell or battery pack exceeds the manufacturer/supplier rating or specifications. Overcurrent may damage the normal operation of the cell or battery and/or induce a hazard.

3.29 overdischarge: The draining of charge from a battery pack after it has been discharged to a normal discharge voltage specified by the cell manufacturer. Overdischarge may damage the normal operation of the cell or battery and/or induce a hazard.

3.30 overvoltage: The situation where the voltage of a cell or battery pack exceeds the manufacturer/supplier rating or specifications. Overvoltage may damage the normal operation of the cell or battery and/or induce a hazard.

3.31 passive authentication: A method of qualification of a battery and/or accessory wherein the end user makes the decision on the compatibility with the host device.

3.32 passive charger: A charger that does not have a communication channel with the host device.

3.33 positive temperature coefficient (PTC) resistor: A component that has the characteristic of a sudden large increase in resistance when the device reaches a specified temperature and/or current.

3.34 product life: The duration in which a consumer can use a product within manufacturers' recommended specifications. Within this product life, the battery provides energy.

3.35 product lifetime: The actual period from initial operation to retirement of a system, structure, or component.

3.36 qualified batteries: Batteries that have undergone analysis and evaluation required by this standard by the cell, battery pack, and host device manufacturer/supplier.

3.37 reasonably foreseeable misuse: Use of a product, process, or service in a way that is not intended by the supplier, but which may result from readily predictable human behavior.

3.38 shelf life: Duration of storage under specified conditions at the end of which a battery still maintains its ability to give specified performance.

3.39 subsystem: A major portion or module that comprises the overall system. Examples of subsystems include, but are not limited to cell, battery pack, host, interface electronics, and end user.

3.40 system: The combined cell, battery pack, host device, power supply or adapter, end user, and environment.

3.41 thermal runaway: The cell condition where the internal cell reactions generate more thermal heat than the cell can dissipate. The condition typically causes cell venting.

3.42 unqualified batteries: Batteries that do not meet the definition of qualified batteries.

3.43 vision system: Inspection technique using a camera or other device (x-ray) that creates and compares information, analyzed by a computing device programmed to evaluate conformance, to a mechanical template and/or dimension and/or color variations, and/or other visual attributes.

4. System integration considerations

4.1 General

This clause sets forth provisions for conducting design analyses for cell, pack, host devices, and power adapters and an overall system-level design analysis of the combination of these, including the end user. The design analyses shall be conducted to minimize hazards (as defined in Annex F) from occurring as a result of one or two independent faults while in intended use, depending on scenario. The analysis shall consider two independent faults for charge and one fault for discharge and storage situations. The design analysis shall also be conducted to minimize hazards from occurring due to reasonably foreseeable misuse.

Table 1 lists several different design analysis techniques that can be used. Conditions beyond reasonably foreseeable misuse are outside the scope of this standard. While design analyses should be thorough, it is not practical to address every conceivable scenario. Such an approach would prove onerous and unrealistic. Furthermore, cell design and manufacturing quality is fundamental to system design safety, as cell faults that create a hazard cannot be mitigated by external subsystems. To minimize hazards, there is no substitute for the use of high-quality cells manufactured in accordance with Clause 5.

Table 1—Example design analysis tools

Failure mode and effects analysis (FMEA)
Fault tree analysis
Empirical and/or destructive testing
Cause-and-effect (fishbone) analysis
Detailed and extensive design reviews
Reviews of prior design issues to ensure they are not repeated
Reviews of industry standards and test methodologies

The design analyses shall identify the following:

- a) End-user responsibilities for reliable total system operation. See Clause 9 for information on the reliable total system operation.
- b) Manufacturer/supplier responsibilities for independent and/or distributed control schemes for reliable total system operation.

In system design analysis, it is necessary to consider all system usage scenarios (charge, discharge, and storage) and the associated affected subsystems. An analysis shall be developed for cell, pack, host, charger, and accompanying accessories that are a part of the system, followed by an analysis that includes the interactions between the subsystems (see Figure 1).

4.2 Specifications and components

The subsystems shall meet the specifications in Table 2. Table 2 shows minimum subsystem analysis tools including system components and the related specifications.

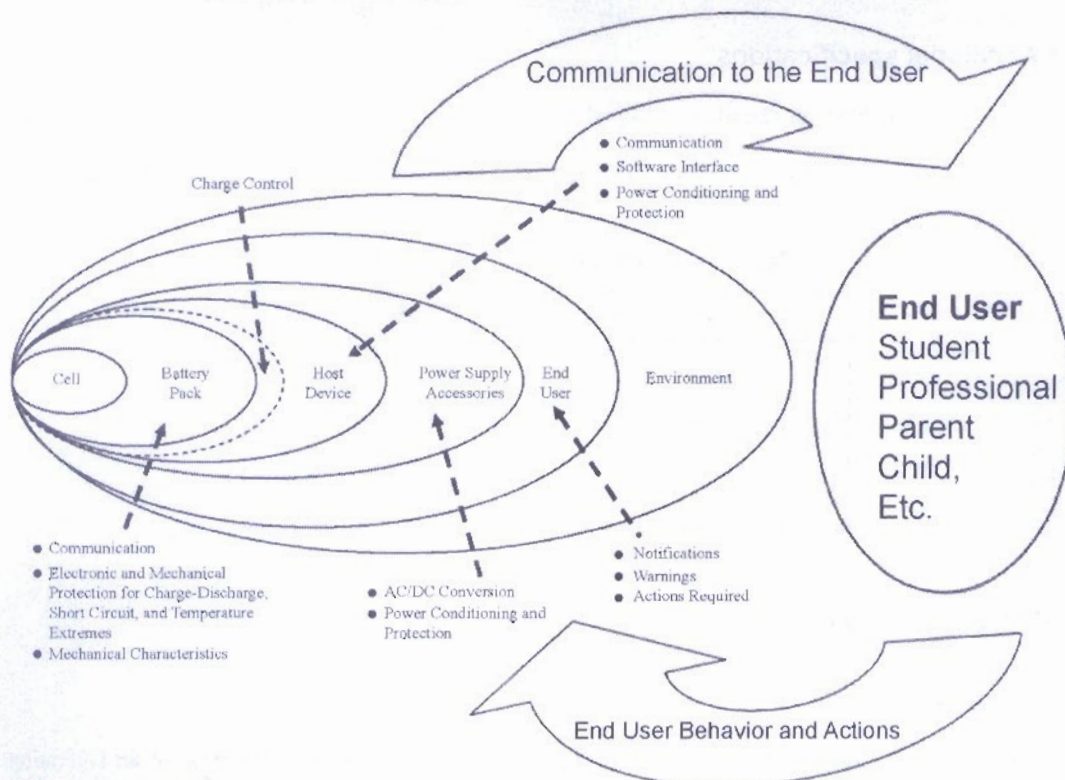


Figure 1—Conceptual diagram of a mobile computing device and its end user.
Examples of functions for each subsystem component are shown

Table 2—Minimum subsystem analysis tools¹¹

System component	Specification(s)
AC/DC adaptor or AC/DC charger	IEC 60950-1:2005; or Appropriate safety standard of destination country
DC/DC adaptor or DC/DC charger	Appropriate safety standard of destination country
Battery pack	UN Manual of Tests and Criteria, Part III, Subsection 38.3, Lithium batteries (ST/SG/AC.10/11/Rev.4-2003) UL 2054
Cell	UN Manual of Tests and Criteria, Part III, Subsection 38.3, Lithium batteries (ST/SG/AC.10/11/Rev.4-2003); and Appropriate safety standard of destination country; and Pass all tests defined by UL 1642-2005 for "User replaceable batteries"

¹¹ Information on references can be found in Clause 2.

4.3 Additional specifications

In addition to the requirements identified in 4.2, subsystems may also be tested to standards shown in Table 3.

Table 3 shows example design analysis tools including system components and the related specifications.

Table 3—Example design analysis tools

System component	Specification(s)
AC/DC adaptor or AC/DC charger	UL 60950-1 UL 1310 [B30]
DC/DC adaptor or DC/DC charger	UL 2089 [B31]
Battery pack	IEC 62133:2002 IEC 61960 [B16]
Cell	IEC 62133:2002 IEC 61960 [B16]

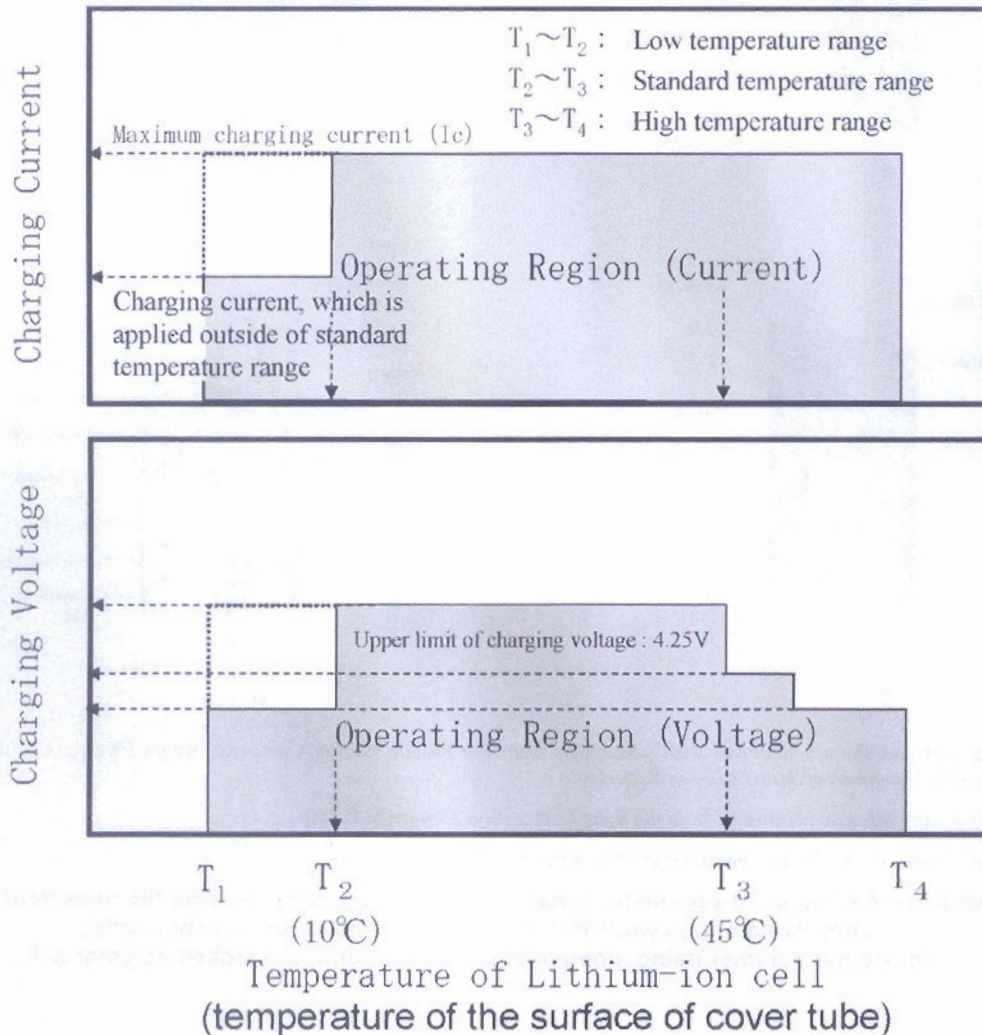
5. Cell considerations

5.1 General

Cell manufacturers/suppliers shall provide cell specifications, incorporating a definition of an Operating region. See Annex E for a template for a Cell specification sheet with minimum content. Cell manufacturers shall define the Operating region of their Li-ion batteries to the pack and system manufacturers. The following describes limits for the Li-ion battery system design; since each chemistry is different, they require varying charging profiles, per specifications. For an example, see Figure 2 for an explanation of Operating region (charging) in which the upper limit for the charging voltage is 4.250 V for common lithium cobalt oxide/graphite in the Operating region for the following temperatures: 10 °C to 45 °C.

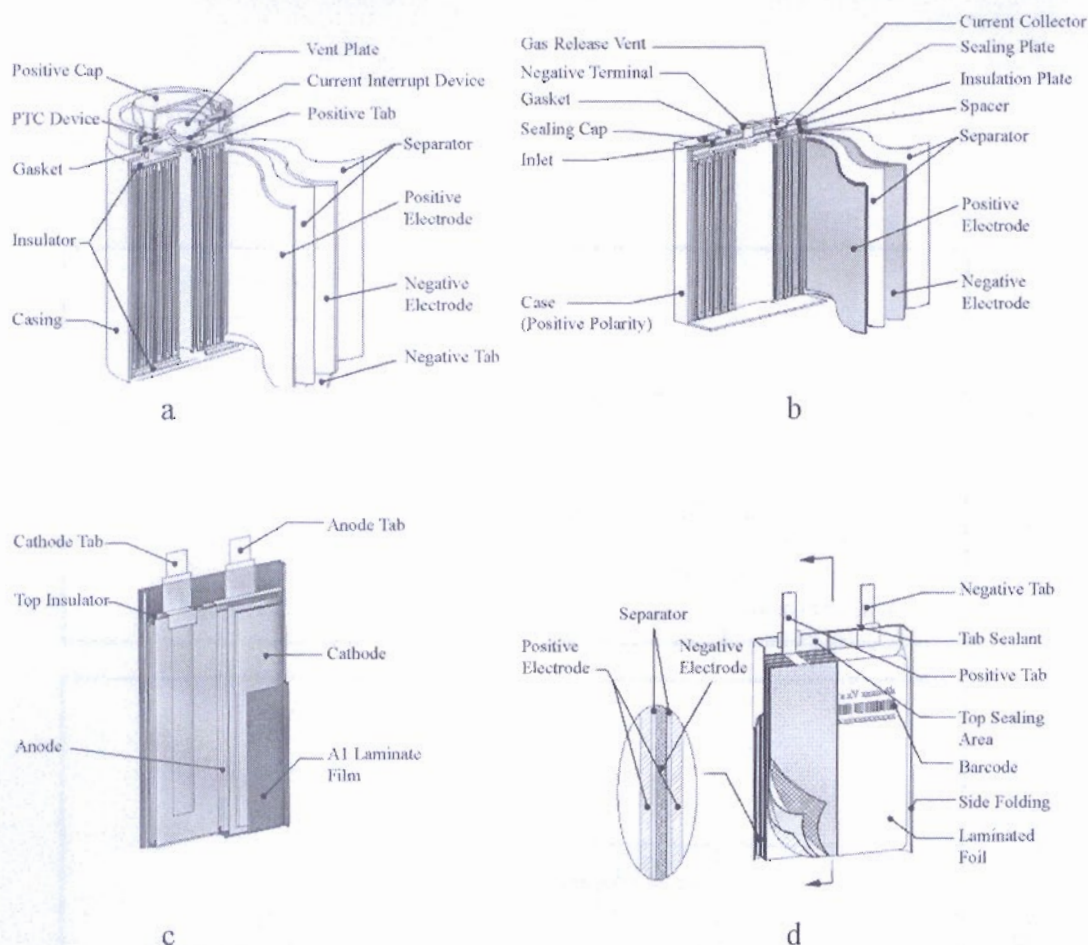
This clause includes the precautions and considerations required for design, manufacturing, and testing of rechargeable Li-ion and Li-ion polymer cells, over their product lifetime, to minimize latent problems. Design parameters shall be of the format: limit + tolerance 1/– tolerance 2, or max limit and min limit, as defined by the cell manufacturer/supplier. For example, if a cell manufacturer/supplier specifies that the voltage of a cell is 4.250 V + 0.000 V/– 0.100 V, the circuit design shall ensure that this maximum is not exceeded. If the measuring device has a tolerance of ± 0.005 V, then the circuit shall be designed to operate to 4.245 V ± 0.005 V, in order not to exceed the maximum. The measurement tolerance should have a 4-sigma confidence.

Figure 3 depicts typical cell construction for cylindrical [part (a) of Figure 3], prismatic [part (b) of Figure 3], pouch prismatic [part (c) of Figure 3], and stacked pouch polymer cells [part (d) of Figure 3].



Reprinted with permission from the Battery Association of Japan, "Guidance for Safe Usage of Portable Lithium-Ion Rechargeable Battery Pack" [B6]. Copyright © 2003.

Figure 2—Example of Operating region (charging)



Part (a) and part (b) are reprinted with permission from the Mobile Energy Company, Sanyo Electric Co., Ltd., *Engineering Handbook of Sanyo's Li-Ion Batteries*.

Part (c) is reprinted with permission from the Sony Corporation. Copyright © 2006.

Part (d) is courtesy of ATL (Amperex Technology Limited).

Figure 3—Examples of schematic construction of Li-ion cells showing the important components: (a) cylindrical; (b) prismatic and Li-ion polymer cells; (c) wound polymer using a pouch construction; and (d) stacked polymer cell

5.2 Design requirements

5.2.1 General

The design process includes definition of nominal cell performance, physical and chemical design parameters, analysis of and mitigation of known and potential faults, characterization of the manufacturing process capability (or specification of processes requirements for the manufacture of a cell), and the initial confirmation of cell performance. The final cell design shall be confirmed. The cell produced shall meet the requirements of the design.

5.2.2 Selection and characteristics of a separator material

5.2.2.1 General

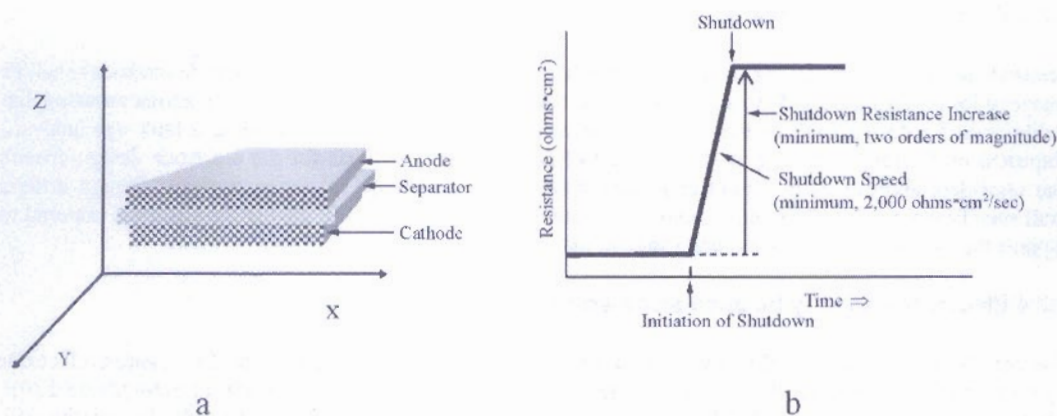
The separator is a critical element in cell construction. As such, the separator physically prevents internal short circuits inside of the cell by separating the anode (negative electrode) from the cathode (positive electrode) and provides a path for ionic current flow inside the cell. The separator also has a safety function that shuts down ionic conductivity inside the cell if the cell temperature increases to abuse conditions. Examples of these functions are depicted in part (a) and part (b) of Figure 4.

5.2.2.2 Stability

The separator material shall have sufficient chemical, electrochemical, thermal, and mechanical stability to meet every requirement of the cell manufacturer/supplier on safety performance for the product lifetime of the cell, under all normal operating conditions. To ensure that separator materials have the appropriate properties to meet expectations of safety performance, the engineering report and separator selections should be reviewed.

5.2.2.3 Shutdown performance

The separator material should exhibit a rapid internal resistance increase (ionic conductivity shutdown) when cell temperature rises above its shutdown point. The separator should have a shutdown resistance increase of a minimum of two orders of magnitude at a minimum speed of $2000 \Omega \cdot \text{cm}^2/\text{s}$. For example, see part (b) of Figure 4. Shutdown performance should be maintained for the life of the cell.



Part (a) has been contributed by John ZHANG of Celgard LLC.

Part (b) is courtesy of Asahi KASEI Chemicals Corporation, Yoshino, et al., *The 34th Battery Symposium*, Japan, 1993, p. 187. Copyright © 1993.

Figure 4—Depiction of the separator (a) positioning between the anode and cathode and (b) the speed and magnitude of change in resistance (shutdown function) on reaching a critical temperature

5.2.2.4 Strength and physical integrity

The selection of the thickness of the separator shall be through the design and qualification. The separator material shall provide adequate strength in all directions with the “Z” direction (normal to the electrode plane) being the most important for cell safety performance. For example, see part (a) of Figure 4. The

separator shall have sufficient physical integrity to withstand handling during the cell manufacturing process.

An engineering analysis shall be conducted to determine if the separator's physical strength provides adequate robustness for handling during cell production and adequate cell safety. The cell manufacturer/supplier shall conduct a design analysis that includes one or more of the following: a FMEA, a fault tree analysis, empirical or destructive testing, or a cause-and-effect (fishbone) analysis to mitigate hazards developing from small faults. For example, in the event of an internal cell short puncturing the separator, the separator or cell structure should prevent the separator melting from increasing the conduction area around the fault. As another example, in the separator selection, an analysis or test should be performed to ensure plastic flow and/or thinning will not compromise the reliability of the cell through the life of the product and under extreme conditions.

5.2.2.5 Shrinkage allowance

The area and width of the separator shall take into consideration allowances for certain separator shrinkage characteristics. The separator/cell design shall maintain adequate coverage of electrodes to meet cell safety requirements. The cell manufacturer/supplier shall conduct a design analysis that includes one or more of the following: a FMEA, a fault tree analysis, empirical or destructive testing, or a cause-and-effect (fishbone) analysis for the separator to consider the allowances to reflect and compensate for a worst case tolerance analysis. This worst case tolerance analysis should prohibit hazards related to shrinkage. Such considerations shall include, but are not limited to, width, alignment, temperature, and any age-related changes in size. For example, the separator should extend beyond the positive electrode and the negative electrode, in all cases.

5.2.3 Electrode design criteria

Electrode design constituents for both the negative electrode (anode) and positive electrode (cathode) shall be designed for performance, safety, and durability in the designated application. The cell manufacturer/supplier shall conduct a design analysis that includes one or more of the following: a FMEA, a fault tree analysis, empirical or destructive testing, or a cause-and-effect (fishbone) analysis for the electrode design criteria that considers allowances to reflect and compensate for a worst case tolerance analysis. Design criteria shall specify material content, purity, and environmental factors, which will enable the electrode material to support the manufacturing process and usage in the end application.

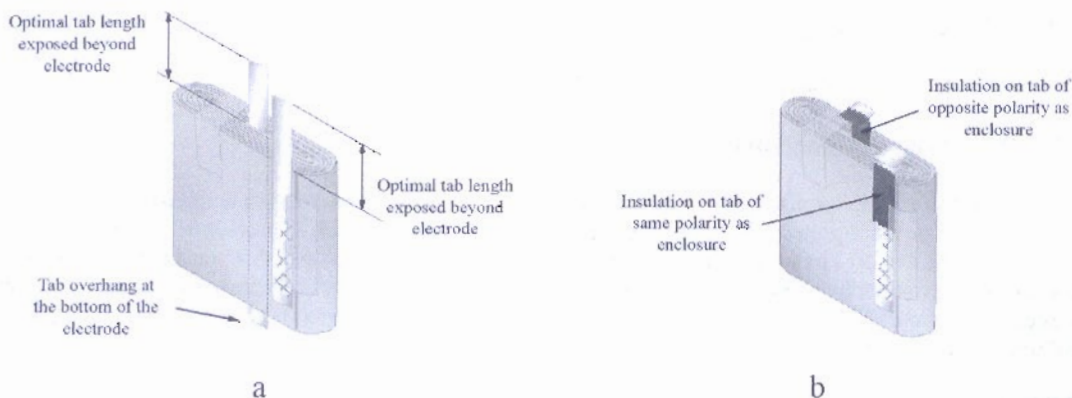
5.2.4 Electrode capacity balance and electrode geometry

The cell design shall ensure that after formation the reversible charge capacity of the negative electrode [Q-reversible (N)] is greater than the reversible charge capacity of the positive electrode [Q-reversible (P)]. Allowance shall be made in the design to maintain the cell balance during the useful life of the cell, regardless of cell geometry and cell charge conditions (temperature, current density, etc.).

The active area of the negative electrode shall completely cover the active areas of the positive electrode. The electrode design shall maintain adequate coverage to meet cell reliability requirements. The cell manufacturer/supplier shall conduct a design analysis that includes one or more of the following: a FMEA, a fault tree analysis, empirical or destructive testing, or a cause-and-effect (fishbone) analysis for the electrode capacity balance and electrode geometry that considers allowances to reflect and compensate for a worst case tolerance analysis. This worst case tolerance analysis should prohibit hazards related to overlap. Such considerations shall include, but are not limited to, width, alignment, temperature, and any age-related changes in size.

5.2.5 Electrode tabs (connection to cell terminals)

The manufacturer/supplier shall establish optimal tab length exposed beyond the electrode for each cell and control to specific tolerance. Tabs shall not overhang the opposite end of the electrodes, except by design. Part (a) of Figure 5 illustrates this principle.



Source: IEEE Std 1725™-2006 [B18].

Figure 5—Cell core showing the tab positioning (a) to demonstrate the optimum length for a particular cell design and (b) to demonstrate an example of positioning the tab insulation to prevent internal shorting of the electrodes

5.2.6 Tab insulation

5.2.6.1 Application of insulation

The tab that has the opposite polarity of the enclosure shall be insulated where it exits the electrode assembly. Insulation shall continue until it reaches the point of attachment to the cell terminal. One embodiment of this principal is illustrated in part (b) of Figure 5. Insulation may be accomplished through one or more insulating schemes. If a tab is located where there is only a one-layer separator to isolate the opposite electrode, additional insulation shall be used, which may be additional layers of separator material or tape.

5.2.6.2 Insulation adherence

Insulation shall be permanently adhered and have good puncture resistance. Use of opaque insulators may be used to facilitate in-process inspection.

5.2.6.3 Insulation characteristics

Insulation material shall have electrochemical, chemical, mechanical, electrical, and thermal stability over the temperature range of use, storage, and transportation as specified by the cell manufacturer.

5.2.7 Cell vent mechanism

5.2.7.1 General

Cell designs shall include a reliable vent mechanism, such as a seam, a score, etc. Appropriate engineering analysis and qualification shall be conducted during the design and prototype phases of cell development. The vent should open at a pressure that is significantly lower than that at which the cell case fails.

Pouch cells do not have a physical vent; therefore, this subclause does not apply to pouch cells.

5.2.7.2 Retention of cell contents

The vent mechanism shall be designed to minimize projectiles and maximize retention of cell contents.

5.2.7.3 Projectile testing

The cells shall pass the projectile test of UL 1642-2005.

5.2.8 Overcurrent protection device

The manufacturer/supplier may employ an overcurrent protector [such as a positive temperature coefficient (PTC) resistor or other protective measure] integrated or built into each cell to protect from hazards in the event of external short circuit and/or overcharge. If the cells are qualified per this standard using a PTC resistor or other protective measure, it shall be included in the cells used in the battery pack design and the manufacturer's qualification of the PTC devices or other protective measure(s) will be done to ensure that the device will operate as intended.

5.2.9 Overvoltage protection

The cell manufacturer shall provide the recommended current to the cell and the upper-limit voltage to the cell, for the appropriate cell overvoltage protection function, at specified temperatures during charge.

5.3 General manufacturing considerations

5.3.1 General

Verification of the proper operation of each critical machine used in the manufacturing process shall be performed at least once per shift. If a change is detected, a root cause analysis shall be conducted to identify the cause for the change and corrective action shall be taken to prevent future occurrences.

5.3.2 Materials specifications

Materials specifications shall be developed to identify and limit impurities to levels below critical limits, as specified by the cell manufacturer.

5.3.3 Impurity avoidance

All known and likely undesirable impurities in materials should be identified, specified, minimized, and controlled throughout the manufacturing process.

5.3.4 Cleanliness of manufacturing operations

The temperature range, humidity, and dust levels shall be specified, controlled, and monitored in the manufacturing environment. Also, environmental management of materials, before and after the manufacturing process, shall be specified and monitored. The introduction of metal contamination from equipment or process shall be prevented.

5.3.5 Manufacturing traceability

The cell manufacturing process shall implement a cell traceability plan. This plan should include a traceability mark that is likely to survive an exothermic reaction during product lifetime and after production to determine lot designation and performance data related to the cell. Use manufacturer/supplier

specifications or documentation to ensure control of this criterion or process. The traceability plan should enable identification of all materials and machinery used in cell assembly. It should enable tracking of all items, including equipment maintenance, which could potentially affect the behavior of the cell produced. Follow documentation requirements consistent with 11.2.

5.3.6 Electrode production process

5.3.6.1 Uniform coating of active materials

Coating density, thickness, and surface roughness (that is, peaks, bumps, and irregularities) of the positive and negative electrodes shall be controlled within the tolerance documented in the manufacturer's specification. The criterion defined in 5.2.4 shall be met in the worst case tolerance. Follow documentation requirements consistent with 11.2.

5.3.6.2 Burr control

The manufacturer shall have an effective method to prevent internal short circuit by burr. Figure 6 shows the schematic cross section of Li-ion cell element to demonstrate the possible occurrences of burr near the electrode edges. Burrs shall not contact any conductive portion of the opposite polarity electrode. In case there is no appropriate burr penetration prevention method in the design (such as the insulation taping at the uncoated foil), each cutting point shall be examined and burr height measured at each shift or lot. Burr height shall be measured and shall not exceed 50% of the lower tolerance limits of the thickness of the separator thickness. In the case of a burr height greater than 50% of the lower tolerance of the separator, documented engineering analysis (such as FMEA) shall show that burr heights with greater limits cannot cause internal shorts. Burr on electrodes shall be measured once per day at a minimum. Follow documentation requirements consistent with 11.2.

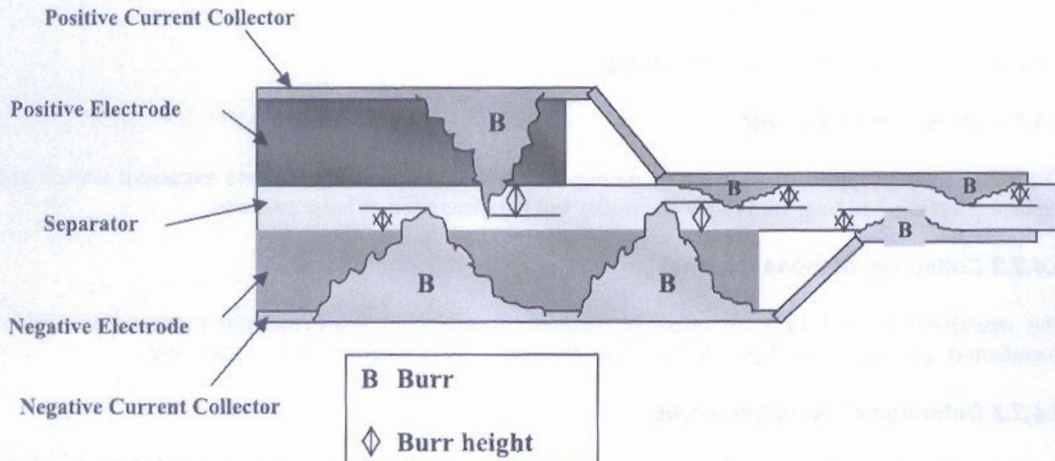


Figure 6—Li-ion cell element cross section showing burr height

5.3.7 Prevention of damage to electrodes

Wrinkling, tearing, and/or deformation of the electrodes should be prevented and eliminated. The manufacturer shall have an effective method for detecting wrinkling, tearing, and/or deformation of all electrode material. An automated vision system may be used for this purpose.

5.3.8 Characteristics of manufacturing equipment

The manufacturing equipment should be designed to prevent any damage or modifications to the cell during manufacturing operations. In-process quality controls shall be implemented to ensure consistent operation of the manufacturing equipment. Follow documentation requirements consistent with 11.2.

5.3.9 Defective electrodes

All electrodes that fail to meet the specification shall be scrapped and shall not be used in the production of cells.

5.3.10 Preventive maintenance plan

Manufacturers shall maintain an effective preventive maintenance plan (including, for example, replacement of cutting knife for slitting electrodes) for all equipment used in the manufacturing processes. Follow documentation requirements consistent with 11.2.

5.3.11 Periodic cell teardown analysis

Cell teardown analysis shall be conducted at least once per machine per shift.

5.4 Spiral winding and stacking process

5.4.1 General

All processes referenced in this subclause apply to assembly of the cell core by spirally wound jelly roll and/or other electrode separator combinations.

5.4.2 Care during winding and stacking

5.4.2.1 Tension and damage

The manufacturer/supplier shall use care during winding and/or stacking to avoid excessive tension and damage (twisting, bending, etc.) to the electrodes and the generation of loose particles.

5.4.2.2 Collection of loose material

The manufacturer shall have an effective method to collect all loose material produced in various manufacturing processes or steps. Methods may include vacuum, magnetic, sticky tapes, etc.

5.4.2.3 Detection of damaged cores

The manufacturer shall have a method to detect nonconforming cell cores. Methods may include high-voltage dielectric test (high-pot), voltage test, resistance/impedance test, and/or aging. A vision system, such as x-ray check, shall be used to ensure electrode integrity at an appropriate point in the assembly process.

5.4.3 Control of electrode spacing

The external dimensions of the cell core shall be adjusted to maintain uniform compression, dimensional characteristics, and no interference that can induce a burr or damage the cell core. The winding spindle removal process shall not damage the jelly roll. Use manufacturer/supplier specifications or documentation to ensure control of this criterion or process. Follow documentation requirements consistent with 11.2.

5.4.4 Uniformity of winding pressure (to core) or stacking pressure (to stack)

The cell core assembly process shall be properly adjusted to remain in the specified range to maintain uniform tension, compression, dimensional characteristics, and to prevent interference that can induce a burr or damage the cell core or stack. Excessive tension shall be avoided to prevent deformation. Use manufacturer/supplier specifications or documentation to ensure control of this criterion or process. Follow documentation requirements consistent with 11.2.

5.4.5 Avoidance of contaminants

The winding process shall prevent introduction of contaminants from the winding process (dust, flakes from electrodes) into the cell. The manufacturer shall prevent introduction of contaminants from the preparation of materials for core or stack including electrode and separator and can or case, as well as through all processes including winding/stacking process to sealing of the cell cap.

5.5 Assembly precautions

5.5.1 Internal short avoidance

The method of assembly for insulating material, whether for electrode, current collectors, or internal insulation, shall provide reliable protection against latent shorts for the product lifetime of the cell. The manufacturer shall provide a method to avoid a short where the bare aluminum foil interfaces with the negative electrode, if it could cause a hazard.

5.5.2 Tab positioning

5.5.2.1 General

The position of negative and positive tabs shall be staggered so that they do not overlap each other. Follow documentation requirements consistent with 11.2.

The assembly process shall prevent deforming tab shapes in a manner that can create jelly roll damage or tab/can short circuits. For example, the insulated tab should be formed into a reproducible shape in such a way that the bent (S-bend typically) sides of the tab are isolated from the walls of the can. Alternatively, an insulator gasket may be included to isolate the tab from the jelly roll and can walls. Tabs positioning to the electrode stack specification should be confirmed by vision system inspection.

5.5.2.2 Integrity of cell core/stack

The integrity of wound or stacked electrodes shall be verified through resistance or a continuity check or equivalent means.

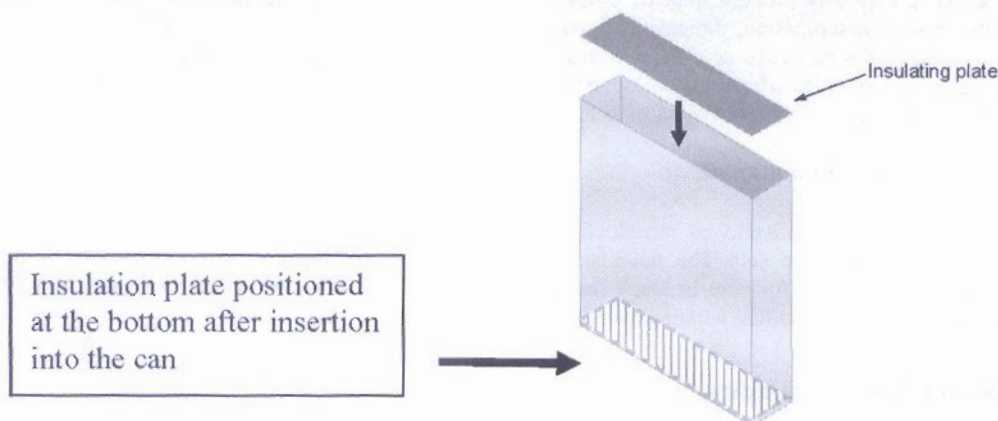
5.5.3 Positioning of insulating plate

If the cell has insulating plates, the insulating plates shall be properly positioned as shown in Figure 7. Insulating material shall be readily visible and should be checked to specification with resistive measurement or other technological means or methods. Use manufacturer/supplier specifications or documentation to ensure control of this criterion or process.

5.5.4 Electrode alignment

The proper alignment of positive and negative electrodes is critical to prevent hazards. The manufacturer/supplier shall ensure the accuracy of electrode placement through in-cell design and in-machine operation to prevent electrode misalignment. The manufacturer/supplier shall ensure that the active material of the positive electrode is aligned and covered by the active material of the negative electrode.

The manufacture/supplier shall conduct 100% inspection by a vision system to ensure alignment. Follow documentation requirements consistent with 11.2.



Source: IEEE Std 1725-2006 [B18].

Figure 7—Positioning of the insulating plate in the bottom of the can to prevent internal shorting to the can

5.5.5 Cell aging and screening

The manufacturer/supplier shall develop and apply appropriate cell aging and screening process. The formation of the cell is one of the most important functions of aging. The other function is the sorting. The sorting criterion shall identify and eliminate early failures.

5.5.6 Qualification of aging process by supplier

5.5.6.1 General

The purpose of this subclause is to provide a method to qualify the effectiveness of the aging test for a cell design. The method is intended to be independent of details of the specifics of a manufacturer's aging test defined in 5.5.5.

5.5.6.2 Aging qualification test

The manufacturer shall have an aging qualification process and test.

The manufacturer shall subject a statistically significant number of cells of a given type to the manufacturer's normal aging process. Those cells that pass shall then be subjected to a sequential series of the manufacturer's aging process to evaluate the effectiveness of the aging process to identify and eliminate early failures.

5.5.6.2.1 Aging qualification testing by the cell manufacturer

The following method is an example that may be used to qualify the aging process:

- a) The cells shall be subjected to the initial defined aging process of 5.5.5.
- b) The manufacturer's method to identify rejected cells shall be used. The rejected cells shall be identified and tracked through the remainder of the qualification process. At the manufacturer's discretion, the rejected cells may be removed from further testing.

- c) The cells shall be subjected to the defined aging process of 5.5.5.
- d) The manufacturer's method to identify rejected cells shall be used. The rejected cells shall be identified and tracked through the remainder of the qualification process. At the manufacturer's discretion, the rejected cells may be removed from further testing.
- e) The cells shall be subjected to the defined aging process of 5.5.5.
- f) The manufacturer's method to identify rejected cells shall be used. The rejected cells shall be identified.
- g) Use acceptance criteria as specified in 5.5.6.2.2.

Figure 8 shows the progress of cells through the qualification process that may be used.

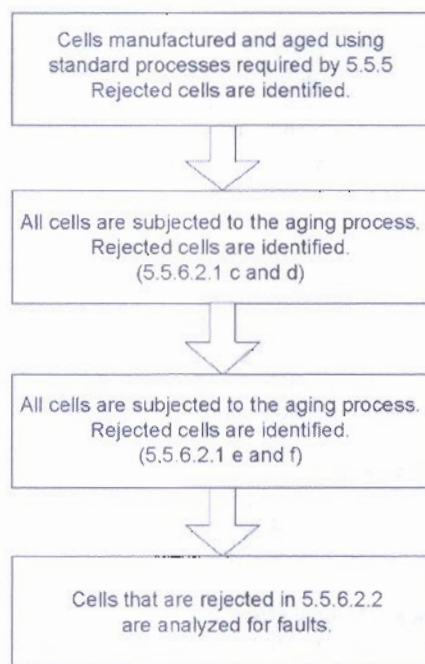


Figure 8—This figure depicts the progress of the cells throughout a qualification process that may be used (see 5.5.6.2.1)

5.5.6.2.2 Acceptance criteria aging qualification

There shall be no additional or different cells identified by the subsequent aging process for those cells that were not identified in the first aging process. If additional or different cells are identified by the subsequent aging process for those cells that were not identified in the first aging process:

- All cells, from the group that is identified as rejected cells by the repeated aging qualification process, should be evaluated (for example, teardown analysis). Cells from a qualified aging process shall not exhibit evidence of separator stains, evidence of shorts, or other faults.
- The source of the fault (equipment, material, process) shall be determined and corrected prior to reevaluation.
- The cause for changes in the identification of the rejected cells at each step of the aging qualification process shall be determined.

5.5.7 Cell leakage

The electrolyte leakage shall be inspected, and leaking cells shall be removed during the inspection process.

5.5.8 Care during cell assembly

There shall be no damage to the cell enclosure or cell case, and critical cell design elements, during welding and other operations. The cell assembly shall be carried out in a controlled environment. Use manufacturer/supplier specifications or documentation to ensure control of this criterion or process. Follow documentation requirements consistent with 11.2.

5.5.9 Disposition of defective material

Rejects/failures (non-cosmetic) identified by any station in the manufacturing process shall be quarantined. Retest or reintroduction onto the production line shall be prohibited. A representative quantity of rejects/failures shall be analyzed per manufacturer/supplier quality system as part of closed loop corrective and preventive action process in order to identify and eliminate root cause. The manufacturer shall have a verifiable destruction plan to ensure failed cells do not reach secondary markets.

5.6 Critical testing practices

5.6.1 General

Preproduction testing and production sampling should be extensive to confirm the design and production process. These testing procedures are not all-inclusive. Tests are designed to confirm that the cells have the desired performance characteristics and are robust enough to resist abuse conditions should they arise.

5.6.2 Qualification of new cell designs

Verification of final product performance and design specification conformance should be conducted through test techniques and product inspection analysis.

New cell designs, including critical changes (see Clause 3), shall pass specified tests identified by the manufacturer/supplier before qualification as production cells. Use manufacturer/supplier specifications or documentation to ensure control of this criterion or process (see Table 1). If the manufacturer/supplier changes the cell design, the manufacturer/supplier shall decide whether or not to requalify the design.

During the initial design, identification of the cell manufacturer shall identify key components, processes and limitations, which, if changed, may increase the hazard of the cell in use. If any of these key components, processes, or limitations are changed, requalification by the cell manufacturer, of the cell, shall be required.

5.6.3 Ongoing testing and qualification of production cells

Production cells shall pass the qualification tests at specified intervals that the manufacturer/supplier specifies to maintain compliance with the manufacturer/supplier internal specification. The manufacturer/supplier specifications and documentation shall be made available at regular intervals, or by request, to verify control of this criterion or process (see Table 1 and 11.2).

WARNING

Some of the tests specified herein can be dangerous to the persons carrying them out. All appropriate measures to protect personnel against possible chemical or explosion hazards should be taken.

5.6.4 Standard tests for cells

There are several relevant cell testing standards. The manufacturer/supplier should be familiar with these standards and should utilize one or more of these standards as part of their testing process. In certain cases, compliance with all relevant standards may be necessary to meet regulatory requirements. Specifications that are relevant are UL 1642-2005 (including the revisions dated June 24, 1999, and October 25, 2004), current revisions of UL 60950 plus derivative standards, and 4.3.3 of IEC 62133:2002.

5.6.5 Cell transportation regulations

The manufacturer/supplier shall comply with transportation regulatory testing requirements including, but not limited to, the UN Manual of Tests and Criteria, Part III, Subsection 38.3, Lithium batteries (ST/SG/AC.10/11/Rev.4-2003).

5.6.6 Cell thermal test

The cell design shall maintain adequate isolation properties during a temperature excursion of at least 1 h or 60 min in the cell in order to maintain safety of the cell. The cell design shall maintain isolation under high-temperature stress conditions for a reasonable period of time to maintain the safety of the cell. The procedure shall entail the testing of five cell samples, randomly selected. Starting at $20\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$, the oven temperature shall be ramped at a rate of $5\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ per minute until it reaches $130\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$. After 1 h at $130\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$, the test is concluded. Cells shall not flame or explode as a result of the conditioning.

5.6.7 Safety test for cycled cells for qualification of cell design

5.6.7.1 General

Five cells, representative of mass production, shall be cycled continuously at $45\text{ }^{\circ}\text{C}$ for 100 cycles as defined by the Operating region in 5.1. The upper-limit charging voltage conditions and maximum charge rate shall be specified on the Cell specification sheet (see Annex E). The discharge shall be specified by the manufacturer/supplier on the Cell specification sheet. The manufacturer/supplier shall specify the cutoff limits on the Cell specification sheet.

5.6.7.2 Cell thermal test on cycled cells

Cycled cells shall be fully charged per the manufacturer's specification before testing. The cells shall be suspended at room temperature in a gravity convection or circulating air oven. Starting at $20\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$, the oven temperature shall be ramped at a rate of $5\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ per minute until it reaches $130\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$. After 1 h at $130\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$, the test is concluded. Cells shall not flame or explode as a result of the conditioning.

5.6.8 External shorting

Five fresh cells fully charged in accordance with the manufacturer's specifications shall be subjected to the short-circuit test of UL 1642-2005.

As a result of the test, the cells shall not explode or catch fire, and the cell casing shall not exceed $150\text{ }^{\circ}\text{C}$.

6. Pack considerations

6.1 General

This clause includes design analysis, manufacturing, and testing of rechargeable Li-ion and Li-ion polymer battery packs to ensure reliable performance over the product life of the mobile computing device. The

objective is to identify the considerations for the battery pack design, manufacturing, and testing to reduce latent problems to a minimum and increase reliable end-user experience. This standard includes battery packs consisting of multiple Li-ion and Li-ion polymer cells connected in series and parallel configurations.

6.2 Pack management

6.2.1 General

All components used in the construction of the battery pack, such as connectors, cables, tabs, insulators, and circuit boards, shall have adequate electrical, thermal, and mechanical ratings for the application.

6.2.2 Components

Cells, components, and materials used in the pack shall be used within their operating limits, as specified by the component manufacturer. Cell suppliers shall provide a Cell specification sheet (including care of cells) to their users that describes cell operation, with minimum content as defined in Annex E. If cell characteristics are considered by the cell vendor to be dependent on the way in which the cells are used, an application-specific Cell specification sheet shall be established and agreed upon between the cell supplier and that user application.

Protection circuit components (excluding cells and thermal devices designed to activate at specific temperatures) shall be rated for a minimum operating range of -25°C to $+85^{\circ}\text{C}$. Continued compliance shall be maintained, for example, through design review and periodic audits or other approaches.

Additionally, protection circuit components shall not fail in a manner likely to cause a hazard if exposed to ambient temperatures of 100°C (see Annex C) for a period of 4 h.

6.2.3 Battery management circuit

6.2.3.1 General

Upper limit for discharge/charge current, voltage, temperature, and time limitations shall be based on conformance to the cell manufacturer's Cell specification sheet identifying these limits. These limits shall be tested on a pack and system that are representative of a production-level pack and system to ensure they conform to the cell manufacturer's Cell specification sheet. Periodic retest of production samples should be performed from time to time to reverify these limits. Circuitry designs that incorporate intermediate voltage taps shall not be employed, except for use in cell monitoring or balancing (see Figure 9). Inspection of the battery circuit schematics and physical samples of the battery shall confirm that intermediate voltage taps are not used.

6.2.3.2 Discharge overcurrent protection

The battery pack shall have at least one overcurrent protection circuit or device designed to meet the requirements of 6.2.6. Overcurrent protect functions may include protection circuitry and devices, such as a fuse or controlled field-effect transistor (FET). This requirement shall be verified through review and testing of the battery pack.

The device may be an integral part of the cell.

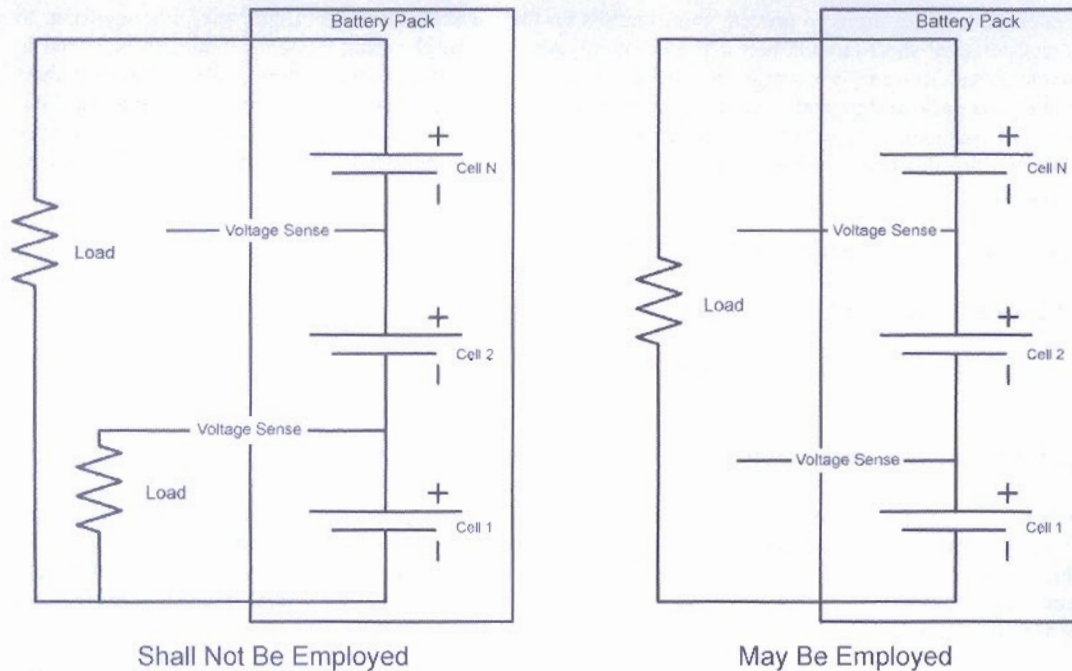


Figure 9—Intermediate tap

6.2.4 Current limiting

6.2.4.1 General

In cases where current limiting is designed into the pack, the upper-limit discharge current and time limitations shall not exceed limits specified in the Cell specification sheet. These limits shall be tested on a representative of a production-level pack to ensure they conform to the cell manufacturer's Cell specification sheet. Periodic retest of production samples should be performed to verify these limits. In systems where current limiting is performed outside of the pack, the pack shall incorporate short-circuit protection.

6.2.5 Layout

6.2.5.1 General

This subclause covers the layout of electrical components in the pack and its effect on the reliability of the pack.

6.2.5.2 Cell connections

Wires conveying cell voltages from series connection points in the packs shall be connected no less than 4 mm from each other, at the point of termination, in order to minimize the likelihood of contaminants, such as excess flux, poorly activated solder paste, or leaking electrolyte, creating a conductive path between the wires. If spacing is less than 4 mm, terminations shall be encapsulated to protect from a conductive path. Similarly, all lines of differing potential should be protected from potential shorts with neighboring lines. This requirement shall be verified by visual inspection of a representative of a production-level battery pack and its associated circuit layout artwork.

In addition to precautions to prevent short circuits on the control board within the pack, it is important to protect potential short circuits between other components within the pack. Spacing should be provided to prevent abrasion, wear, or damage to cable leads and/or connectors in the battery pack. To prevent short circuits, the pack design shall ensure that any un-insulated conductors (such as bare wires, exposed tabs, etc.) will maintain a separation of more than 1 mm from other conductive surfaces through industry standard drop/shock and vibration tests. Any conductors that do not maintain this separation shall be insulated.

If the design of the sense lines limits current, the spacing requirements would be considered to be met.

6.2.5.3 Parts clearance

Electrical parts should have appropriate clearance to allow for situations where the battery pack is deformed by external mechanical force.

6.2.5.4 Accidental short circuit

In order to minimize the occurrence of an accidental short circuit, the design of the battery pack circuit board shall provide adequate runner spacing, soldering pad area size, and distance between solder pads. This requirement shall be verified by visual inspection of a representative of a production-level battery pack and its associated circuit layout artwork. A design failure mode and effects analysis (DFMEA) or equivalent can be used.

In order to minimize the occurrence of an accidental short circuit, the following shall be implemented in the design of the circuit board and the assembling process of battery packs:

- a) Provide runner spacing of ≥ 0.0254 mm per 5 V, and follow guidelines provided in IPC-2221. This requirement shall be verified by inspection of a representative of a production-level battery pack and its associated circuit layout artwork.
- b) Provide adequate process control from solder balls, solder flashes, solder bridges, and foreign debris, as outlined in IPC-A-610. This requirement shall be verified by inspection of a minimum of three representatives of a production-level battery pack from different lots per battery assembly location.

Exposed tracks or vias or solder pads or other electrically conductive material carrying any currents should be spaced to minimize the likelihood of contamination bridging tracks of different electrical potential causing current to flow between the tracks. A solder mask is not considered to be insulation.

6.2.5.5 Isolation of control circuits

Battery management circuit in battery packs should be thermally isolated from the cells in order to preserve diagnostic information on the board. The board, and particularly the chip storing diagnostic information, should be placed away from the vent path of pack cells.

6.2.6 Short circuit

6.2.6.1 General

The battery pack shall limit output current in the event of an external short circuit, whether the battery pack is installed in or is outside the host device for end-user removable battery packs. This requirement shall be verified by test of a representative of a production-level pack.

6.2.6.2 Connector design

Battery pack connector designs shall be implemented to minimize the possibility of accidental external short circuit.

6.2.7 Fault handling

When voltage, current, temperature, or other defined condition is exceeded, action shall be taken to mitigate hazards. Such conditions could be a combination of multiple factors.

The action shall be one of the following:

- a) Restriction in use (for example, reduced capacity or charge rate)
- b) Temporary disabling of a function or functions within the pack or host (for example, disable charge if temperature is too high)
- c) Permanent disablement of the pack

The battery management circuit should attempt to communicate the nature of the fault to the host.

The battery pack response to conditions that are out of specification shall be tested on a pack that is representative of a production-level pack to ensure they conform to the Cell specification sheet or design of the pack.

6.2.8 Temperature monitoring

The host and pack manufacturer should jointly determine the temperature profile of the pack and determine where to place temperature sensors based on extreme temperatures. In the case of a single-pack temperature measuring point, the temperature sensor should be placed on the appropriate cell with good thermal contact.

6.2.9 Charge voltage

The host, battery, or a combination of the two shall be designed to prevent voltage and current in excess of the cell specifications. Charging to a higher capacity and/or voltage than specified by the cell manufacturer is prohibited.

Circuits and devices shall take into account measurement tolerances to ensure that the maximum cell voltage is not exceeded.

6.3 Cell management

6.3.1 General

This subclause refers to operational limits within which the cells shall be maintained both as single cells and as components in a pack.

Battery pack response to excessive voltage and current shall be tested on a pack that is representative of a production-level pack to ensure it conforms to the cell manufacturer's Cell specification sheet. Periodic retest of production samples should be performed to reverify the battery pack response.

6.3.2 Cell matching

6.3.2.1 General

The blocks of series-connected cells in a pack shall be matched per specification for voltage, capacity, and size.

6.3.2.2 Cell sourcing

Cells in series-connected blocks shall be from the same manufacturing lot(s).

6.3.2.3 Cell conformation

6.3.2.3.1 General

The cells shall not be connected in cell blocks and series of blocks in a battery pack in the combinations given in 6.3.2.3.2, 6.3.2.3.3, and 6.3.2.3.4.

6.3.2.3.2 Old and fresh cells

Cells shall not be connected in cell blocks and series of blocks in a battery pack using a combination of old and fresh cells.

6.3.2.3.3 Different cell manufacturers

Cells shall not be connected in cell blocks and series of cell blocks using a combination of cells made by different manufacturers.

6.3.2.3.4 Reworked cells

Cells shall not be connected in cell blocks and series of cell blocks using a combination of cells comprised of cells reused from previously built assemblies. Once a weld has been removed from a cell, the cell shall be discarded and destroyed to prevent entrance into the secondary market.

6.3.3 Cells that are different in construction or capacity

Different types of cells should not be used in the same pack in a manner that leads to a hazard. Pack designs shall document the analysis of the behavior of cells of different types used in the same pack.

6.3.4 Cell monitoring

6.3.4.1 General

Temperature ranges for operation shall be set based on the operating temperature ranges recommended by the cell, battery pack, and host device manufacturers/suppliers.

6.3.4.2 Short detection

Nascent shorts may be detected by measuring excessive self-discharge of cells, or the ac impedance of cells.

6.3.4.3 Detection of open circuit cells

Open circuit cells may be detected by measurement of unusual voltage behavior of one cell block versus another.

6.3.5 Before charge requirements

Before charge is initiated, the pack/host shall check to determine if the pack is within the conditions for operation specified by the cell manufacturer/supplier and should check that the battery is an authorized battery pack. Charging shall be conducted in accordance with the conditions specified on the Cell specification sheet.

6.3.6 Charge

6.3.6.1 General

The maximum charging voltage measured at the cell block shall not exceed the value specified on the Cell specification sheet. Accuracy of measurements shall be taken into account to ensure that safe limits are not exceeded. For example, if ± 10 mV is the tolerance on charge cut-off voltage measurement, then the cutoff should be set 10 mV below the cell specification.

6.3.6.2 Location of charge control

Charge control may be located in the battery pack.

6.3.6.3 Redundant overvoltage protection

The battery management circuit shall incorporate at least two independent cell/cell block overvoltage protection functions, in addition to voltage limits designed into the charging circuit. At least one of the overvoltage protection functions shall be in the pack (see 6.2.9). The independent circuits shall protect each cell/cell block from overvoltage in the event of a failure of the primary circuit.

6.3.6.4 Monitoring of each cell block

The combination of cell, battery pack, and host device/charger shall detect the voltage of each cell block in the battery pack and shall control the charge if overvoltage occurs.

The charge voltage of the cell block should be controlled to the specified standard charge voltage. The first protection circuit should recognize that any cell block has reached the specified maximum charge voltage and cease charging the cell blocks.

Charging may resume at a specified overvoltage recovery level, which shall consider both voltage and time.

The second protection circuit shall monitor the voltage of the cell blocks. If the cell voltage rises beyond the maximum charge voltage to the cell critical voltage, the pack shall be permanently disabled from charging.

6.3.6.5 Abnormal cells

In the design of the pack management, manufacturers should consider methods to detect or predict cell abnormalities and other conditions that may lead to hazards; such abnormalities may include, but are not limited to, abnormal self discharge, abnormal impedance, abnormal capacity, abnormal temperature, etc.

6.3.6.6 Recovery from overdischarge

If a cell, or cell blocks, has been discharged beyond the expected minimum state, the pack/system shall follow the cell manufacturer's recommendation to recover from this condition.

6.3.7 Discharge

6.3.7.1 General

The minimum discharge voltage and maximum discharge current shall be set on the basis of a Cell specification sheet (see Annex E) as specified by the cell and pack manufacturer/supplier.

6.3.7.2 Overcurrent precautions

The upper-limit discharge current and time limitations shall be set on the basis of the system analysis in Clause 4. The battery pack shall have at least one overcurrent protect circuitry or device. The system analysis shall define a maximum current that the system can handle.

6.3.7.3 Undervoltage protection

The pack shall have at least one undervoltage protection circuit that disables battery discharge to the external system. Use the undervoltage value provided on the Cell specification sheet.

6.3.7.4 Low cell voltage cutoff

The pack shall cease to provide power or the host shall cease to draw power from the pack if any cell block is detected with a voltage equal to or less than specified by the cell manufacturer.

6.3.7.5 Low-voltage power-down

In the event that the voltage of one or more cell blocks reaches the minimum operating voltage as specified by the cell manufacturer, the battery management circuit shall maintain a low-power state in order to minimize further discharging of the cells.

6.3.8 Cell balance

6.3.8.1 General

This subclause refers to the need to monitor the balance of the state of cells in the pack.

6.3.8.2 Cell monitoring

Blocks of parallel wired cells connected in series shall be monitored to compare the voltage of each cell block. When cell blocks differ by more than a specified limit under specified conditions, the battery pack shall be disabled.

6.3.9 Cell temperature

6.3.9.1 General

Charging shall be terminated if the temperature of the hottest cell exceeds the maximum safe charging temperature specified by the cell manufacturer.

The host/pack shall monitor the temperature of the pack during discharge (hottest cell) and ensure that this does not exceed the maximum temperature, as specified by the cell manufacturer. In the event that this temperature is exceeded, the pack shall cease to provide power.

6.3.9.2 Detection of hot cell

Temperature sensors may be placed on each individual cell in a pack in order to detect unusual temperatures during charge or discharge. Localized heating might come from a cell fault, from external heating by the system, or by the end user placing the equipment close to a heat source.

6.3.10 Cell changes over time

The cell performance on charge and discharge changes with cycling and age. The battery management circuit may change control points of temperature, current, and voltage to improve end-user performance as the cells age.

6.4 Information transfer

6.4.1 General

This subclause outlines methods for reliable communications between the pack and the host. The exact nature of the communications is not specified in this standard. The industry “smart battery system” standard [B27] is a good example of communications and may be augmented with further status messages from the pack.

6.4.2 Data model

6.4.2.1 General

The battery management circuit should use a model of the cell performance to assist in the reliable operation of the battery pack and the reporting of potentially hazardous situations.

6.4.2.2 Communication of error messages

The battery management circuit and host shall communicate on a regular basis—not less frequently than every 5 s. The communication shall advise the host of the condition of the pack.

The host/pack combination shall communicate potential battery issues as they occur. In cases where a hazard may result, the battery shall fail-safe. In the event that the system does not respond within a defined time period to a message indicating a potential hazard, the pack shall take action independent of the host (see 6.2.7).

Conformance shall be ascertained by demonstrating arrival of messages to the host system.

6.4.2.3 Storage of battery history

The battery management circuit should store key behavioral data such as time, cell block voltages, current, and temperature within the battery pack. Information should be maintained for at least the last three charge terminations and include reason for termination, temperature, time, cell block voltages, and current. This data should be stored in non-volatile memory. This may be demonstrated by recovery of such data from a production pack.

6.4.3 Alternate signaling

Battery packs utilizing signaling between the pack and the host should provide an alternative signal or other fail-safe method for pack operation safety in the event of a failure of the primary signaling method.

6.4.4 Alternate standard

The commonly used “smart battery system,” and “system management bus,” or subsets thereof, are not requirements of this standard. This standard does not require autonomous battery monitoring inside the battery pack. However, the system as a whole shall ensure proper management of the battery pack including, but not limited to, the ability to identify the insertion of a different pack and identifying its state of charge (SOC). When two packs of differing SOC are swapped between two systems, those systems shall clearly determine the correct SOC of the new battery.

6.5 Mechanical design

6.5.1 General

The mechanical design of a battery pack has several important purposes from a structural integrity and reliability point of view. The mechanical package should be designed to ensure that the effect of an external mechanical force, including press, bend, twist, drop, vibration, and shock, on battery packs does not compromise the reliability of the pack. Electrical parts within the pack should have appropriate clearance to allow for situations where the battery pack is deformed by external mechanical force. The design practices of 6.5.2 through 6.5.8 shall be followed.

6.5.2 Cell dimensions

6.5.2.1 Cell mechanical fit

Individual unit cells should be placed in the battery pack with considerations to include orientation, insulation, spacing, and other elements from the design analyses. Soft-battery packaged cells (for example, Li-ion polymer) require special mechanical considerations.

6.5.2.2 Prevention of shifting cells

Cells shall be located within the pack in a manner that will minimize shifting, such as location tabs in the pack casing, padding between cells (insulating), or adhesive.

Allowances shall be made for cell and battery pack dimensional tolerance and changes throughout the product lifetime so as not to compromise the safety of the pack. Design analysis shall demonstrate the following:

- a) Cells with the minimum expected dimensions will be unable to shift under normal usage conditions. Minimum dimensions shall be determined from Cell specification sheets and are typically present at a low SOC.
- b) Cells with the maximum expected dimensions will fit into the pack without the need for unreasonable insertion force, and with no distortion to the pack. Maximum dimensions shall be determined from the Cell specification sheets, and will typically refer to an old and fully charged cell.

6.5.2.3 Connection spacing

Appropriate spacing shall be provided to prevent abrasion, wear, or damage to cable leads and/or connectors in the battery pack.

6.5.2.4 Strain relief

Strain relief should be provided for cable leads and/or connectors inside the battery pack.

6.5.3 Cell orientation and isolation

6.5.3.1 Cell orientation

Cells should be oriented such that the vents are pointing away from the likely location of the end user. Individual unit cells in a battery pack shall be arranged in accordance with correct polarity.

To the degree possible within the constraints of the form factor of the battery pack, cell vent mechanisms should be oriented such that they will not force hot vent gasses from an exothermically failing cell onto neighbor cells in the battery pack.

6.5.3.2 Vent mechanism

The vent mechanism of the cell shall not be covered or obstructed with plastic or other material in the battery pack in such a way as to prevent its operation. If the pack construction allows material (for example, epoxy, potting material) to come in direct contact with the outlet area of the cell vent, then a venting test shall be conducted to show that, in the case of a venting cell, the pack will not prevent the escape of gasses from any cell in the pack.

6.5.3.3 Cell insulation

Cells at a different electrical potential shall be electrically insulated from each other to prevent unintended shorting together. Cell sleeving is not an adequate insulation between differing potential voltages.

6.5.4 Cell connections

6.5.4.1 General

Tabs, plates, and lead cables should be connected by welding and/or soldering to provide secure mechanical and electrical connections. Connections shall not be soldered directly to the cells.

6.5.4.2 Welding of tabs

Welding of tabs should be done with greater than two welds in order to minimize the potential of an open circuit due to tears or poor welds.

6.5.4.3 Retention and strain relief of tabs

Current carrying tabs attached directly to the battery control board should ensure proper retention and strain relief.

6.5.4.4 Testing weld strength

Tab welds for cells shall have specified strengths and should be periodically tested to ensure that they meet minimum specified strength requirements.

6.5.4.5 Welding placement

Welding shall only be applied in areas designated by cell manufacturer/supplier in accordance with agreed upon specifications.

6.5.4.6 Protection from the assembly process

The circuit board, cells, and components should be adequately protected from ultrasonic weld energy and/or other battery assembly process.

6.5.5 Internal pack connections

6.5.5.1 General

A battery pack shall be designed to protect against unintended electrical connections between the circuit board and other electrical components and devices.

6.5.5.2 Tab insulation

Insulating materials should be deployed to prevent shorting of current carrying tabs to cells.

6.5.6 Electrolyte leakage

The battery pack shall be designed to ensure that any electrolyte leakage from the cells does not interfere with the proper operation of safety provisions within the pack. Methods may include encapsulation of the electronic circuitry, printed circuit layout and spacing of components, mechanical orientation of the cell vents, etc.

6.5.7 Physical connection

6.5.7.1 Connector design

Connector/terminal shall be designed to minimize the possibility of accidental short circuit. Electrical connector/terminal should set back in its housing to prevent shorting by contact with a conductive object.

6.5.7.2 Connector compatibility

Connector/terminal shall adhere to host device mechanical considerations (see 7.8.3.1). Packs shall be constructed to mechanically prevent reverse-polarity insertion into the host device. This may be achieved by inclusion of a key in the connector or by other means.

6.5.8 Pack enclosure openings

Pack enclosure openings shall be designed such that potential hazards due to foreign debris entering the pack will not result in the compromise of the protection circuit or shorting of circuits or components. The pack enclosure shall allow for the venting of pressure from the pack in the event of a cell rupture. Packs shall comply with IEC 60950-1:2005 with regard to enclosure openings.

6.5.9 Integrity of enclosure joint

Closure and sealing of the final pack assembly should utilize effective welding or non-reactive adhesives, or equivalent methods, in order to prevent separation of the pack enclosure by normal abuse and reasonably foreseeable misuse.

6.6 Identification

6.6.1 General

This subclause covers the identity of packs through labeling, electronic identification, and verification. This is important for initial verification of the authenticity and anticipated quality of the pack and also for identification of packs in the event of an issue developing.

6.6.2 Marking

6.6.2.1 General

Each battery pack shall carry external markings providing the information given in 6.6.2.2 through 6.6.2.8 at a minimum.

6.6.2.2 Part number

The identification shall include the name or part number of the battery pack.

6.6.2.3 Voltage

The identification shall include the typical voltage as rated by the manufacturers/suppliers of the battery pack. The maximum voltage as rated by the manufacturer/supplier of the battery pack may be included.

6.6.2.4 Pack capacity

The identification shall include the nominal capacity of the pack specified in watt-hours.

6.6.2.5 Chemistry

The identification shall include the chemistry type of the battery.

6.6.2.6 Pack manufacturer/supplier identification

Name or identification code of the battery pack manufacturer/supplier shall appear on the pack.

6.6.2.7 Agency approvals

The battery pack should be certified in accordance with the rules and regulations of relevant and applicable regulatory organizations of the geographical region(s) where the battery pack will be sold. The battery pack may be marked with certification logos supplied/promoted by these safety organizations.

6.6.2.8 Unique identifier

Each battery shall include a unique serial number that is capable of being electronically and visually read to enable identification of the pack sufficient to track critical components.

6.6.3 Traceability

Each manufacturer/supplier shall have a traceability plan for critical components and cells.

6.6.4 Authentication

6.6.4.1 General

The pack shall implement an authentication method to allow the system to verify that it is a qualified pack.

6.6.4.2 Identification code

The battery management circuit shall contain an electronically readable identification code. This code shall enable traceability and may be a duplication of the unique identifier.

6.6.4.3 Implementation by manufacturer/supplier

There are multiple methods of implementing authentication in a system. The specific method of authentication to be implemented is left to the discretion of the system's manufacturer/supplier.

6.6.4.4 Authentication of accessories

The use of authentication mechanisms described in 6.6.4 should also be considered for other external accessories such as power sources, charging docks/cradles, and USB interface devices.

6.7 Environmental considerations

6.7.1 General

This subclause outlines potentially adverse conditions to which a pack may be subjected and recommends methods to increase the tolerance to such conditions, in order to maximize the reliability of the packs.

6.7.2 Thermal

6.7.2.1 General

Over-temperature protection shall be incorporated to prevent operation outside temperature limits as agreed upon by cell, battery pack, and host manufacturers/suppliers. Operating temperature limits may be based on current levels and time periods and may be different during the charge and discharge phases. See 7.6 for additional details.

6.7.2.2 Ambient temperature

Temperature ranges shall consider ambient temperature as well as the effects of heat interactions between cell, battery pack, and host device.

6.7.2.3 Over-temperature protection

The battery pack shall contain at least one thermal protection circuit or device independent of internal cell devices or mechanisms (see 6.2.3, 6.2.8, and 6.3.9). The combination of cell, pack, and host device/charger shall have at least two independent thermal protection devices or mechanisms.

6.7.2.4 Over-temperature action

When temperature limitations are exceeded, the system (battery pack, host, or both) shall take action, which may include shutdown, or other protective action (see 6.2.7).

6.7.3 Electrostatic discharge

Specific electrostatic discharge (ESD) tolerance shall be included in the battery pack design, testing, and qualification. Test procedures described in IEC 61000-4-2 [B14] may be used.

6.7.4 Altitude

The pack shall meet the requirement for altitude as specified in IEC 62281.

6.7.5 Humidity

In high-humidity environments, microscopic droplets of water can deposit onto the insulation thereby weakening the electrical isolation between conductors. In some applications, a conformal coat may be required on the battery management circuit board. Hygroscopic material shall not be used as insulation.

6.8 Assembly/manufacturing

6.8.1 General

This subclause ensures that the pack is properly built on the production line.

6.8.2 Factory

The factory shall be maintained as a clean and orderly environment per the manufacturer's/supplier's quality system to prevent contamination of the end product, which may affect its operation.

6.8.3 Manufacturing process

6.8.3.1 Solder joints

Precautions shall be implemented to ensure sufficient solder flux activation to avoid incomplete solder connections, particularly where hand-soldering is practiced. Refer to IPC-A-610 for industry standard solder workmanship.

6.8.3.2 Component protection during pack assembly

Precautions shall be taken to avoid damage to cells, battery management circuit, and battery pack during manufacturing, including ultrasonic welding.

6.8.3.3 Manufacturing considerations

Precautions shall be taken to avoid damage to conductors and insulators, for example, from sharp edges, burrs, pinching, or kinking.

6.8.3.4 Protection from electrostatic discharge

Precautions shall be taken to avoid damage to protection circuits and other devices from electrostatic discharge (ESD) during handling.

6.8.3.5 Protection function verification in process

Protection functions shall be verified per the documented manufacturer/supplier process.

6.8.3.6 Adherence to process control

Critical processes such as welding shall have a quality control and a maintenance plan to control the consistency of the assembly process and adherence to specifications.

6.8.3.7 Welding operations

There shall be no damage to cell container and critical cell design elements during welding and other operations.

6.11.3 Testing

There are several relevant battery testing standards. Manufacturers/suppliers shall be familiar with these standards and shall utilize one or more of these standards as part of their testing process. Refer to 4.2. In certain cases, compliance with one or more of these standards may be necessary to meet regulatory requirements. Relevant standards include the most recent editions of the following safety standards: UL 2054, UL 60950-1, IEC 62133, and the transportation tests and requirements for lithium batteries outlined in the UN Manual of Tests and Criteria (ST/SG/AC.10/11).

6.11.4 Ongoing reliability testing

To maintain compliance with the internal specification of the manufacturer/supplier, packs manufactured on the current process of record shall pass the qualification tests at intervals specified by the manufacturer/supplier.

6.12 Production testing

6.12.1 General

Prior to shipment, 100% of outgoing packs shall be tested for functionality. In addition, samples shall be tested as follows.

6.12.2 Sample sizes

All tests shall be carried out on a statistically valid number of samples. For example, the manufacturer may refer to ANSI/ASQ Z1.4 [B2] and ANSI/ASQ Z1.9 [B3].

6.12.3 Sampling methods

Test samples should be selected at random throughout one manufacturing day.

6.12.4 Data recording

Records of the samples and test results shall be maintained for the expected life of the product.

6.12.5 Test methods

6.12.5.1 General

Test methods shall be agreed upon by the pack and host manufacturers. They may be selected for the tests listed in 6.11.3 and may include specific tests requested by the host manufacturer.

6.12.5.2 Drop test

Packs shall pass the drop impact test of UL 2054. In addition, refer to 7.8.8 for the drop test, which shall be conducted with the pack inside the host.

6.12.5.3 Vibration test

The pack manufacturer shall ensure that the pack complies with the vibration test specified in IEC 62281. Refer to 6.13.1.

6.12.5.4 Tab welding

Samples from the tab welding station shall be taken and subjected to a pull test. The pull force for verifying the tab weld integrity should be established by the pack manufacturer based upon the materials, process used, and application requirements.

6.12.6 Interpretation of results

The results of the various tests shall be correlated and compared to results of previous tests. The root cause for any change in test results should be identified and corrective action taken if warranted.

6.13 Storage and shipping

6.13.1 General

Storage and shipping are critical items in maintaining high-quality cell and pack performance in mobile computing devices. Attention to the details of storage conditions as recommended by the cell manufacturer is essential.

6.13.2 Storage

Packs should be stored in a controlled environment before shipping, in accordance with the pack manufacturer specifications.

6.13.3 Conditions for shipping

6.13.3.1 Adherence to transport regulations

The manufacturer/supplier shall comply with transportation regulatory testing requirements including the appropriate sections of the UN Manual of Tests and Criteria (ST/SG/AC.10/11/Rev.4-2003).

6.13.3.2 State of charge for shipping

The battery should be shipped at partial-charge state when shipped in bulk (three or more packs not in a system). The manufacturer should ship packs at a state of charge (SOC) of 50% maximum, in order to limit the energy available to drive faults and ensure extended storage life prior to self-discharge precipitating issues from low cell voltages.

7. Host device considerations

7.1 General

This clause includes considerations to include in the analysis of designing, manufacturing, and testing of host devices for use with rechargeable Li-ion and Li-ion polymer battery packs over their product lifetime. The objective is to identify the considerations for the host system design to minimize latent problems and to enhance reliable end-user experience. Certain requirements of Clause 6 may be met by incorporating the appropriate function in the host device rather than the battery pack. Host device manufacturers/suppliers should be familiar with Clause 6 and verify that the appropriate system-level functions are expected to reside in the host, pack, or cells.

The upper limit for discharge/charge current, voltage, temperature, and time limitations shall be based on conformance to the cell manufacturer's Cell specification sheet, which identifies these limits. These limits

shall be tested on a production-level battery pack and system, when appropriate, to ensure they conform to the cell manufacturer's Cell specification sheet.

7.2 DC input voltage and current to the host device

7.2.1 Input

Each host device should be marked with, or otherwise indicated, the specified input voltage range and the maximum current for the system. The host device shall not allow damaging power surges and transients from the input to propagate to the battery pack. Specific surge and transient limits shall be included in the system design specifications.

7.2.2 Overvoltage

The host device shall be designed to indefinitely withstand the maximum voltage from the adapter, under a single fault condition, to prevent a cascading failure through the system to the battery pack and/or cell.

The maximum input voltage specification should consider the potential use of unqualified, mechanically compatible adapters.

7.2.3 Overcurrent

The host device or system shall ensure that the battery is not charged with a current greater than the maximum charge current specified by the battery manufacturer.

The system (consisting of battery cell, battery pack, and host device/charger) shall contain at least two independent discharge overcurrent protection functions. This requirement shall be verified by test of a pack representative of a production-level pack (see Clause 4) installed in a system if necessary to engage all overcurrent protection mechanisms. One may be at the cell level. Overcurrent protection functions may include protection circuitry and devices, such as a fuse or PTC resistor.

7.2.4 Fault isolation and tolerance

If the system design allows overvoltage or overcurrent (under a single fault event) to propagate to the battery pack, the pack shall withstand this overvoltage and/or overcurrent.

The host device or system may isolate the input connection from the rest of the system if the dc input voltage and/or current exceeds specified values, plus certain tolerance. The tolerance should be decided by the system manufacturer/supplier.

7.3 Charging subsystem considerations

7.3.1 Safety

The charging system, or any part of the host device, shall not disable or override the safety features inside the battery pack. The host/pack shall follow the recommendations on the Cell specification sheet.

7.3.2 Pack identification

An identification scheme shall be employed so that the host device can identify that the battery pack is qualified for use within the system. The identification scheme shall communicate or indicate the maximum charge voltage. If the battery pack cannot be properly identified, charge shall be terminated. Discharge may be terminated. In addition to an identification scheme, a mechanical interlock that will impede the installation of an improper pack should be incorporated as well.

7.3.3 Algorithm verification

The charging subsystem shall identify the type of battery pack and execute the correct charging algorithm based upon the identification information provided by the battery pack. The charging system shall not charge the pack above the maximum charge current and voltage conditions as specified by the pack manufacturer/supplier.

7.3.4 Precharge

A precharge algorithm may be applied to a low-voltage or low SOC battery pack to activate a controller/host.

7.3.5 Communication fault

In charging subsystems that employ an electronic communications interface with the battery pack, the system shall disable charging if communications fails.

The controller may receive periodic update information from the battery pack. If the battery pack fails to provide the periodic update, the controller shall notify the host to stop charging after a predetermined period. The period between updates and the number of updates dropped before a fail condition is reached is determined by the system manufacturer/supplier.

7.3.6 Temperature qualification

The charging system shall monitor the battery temperature prior to, and during, the charging process. If the temperature is out of range, the system shall suspend charging.

7.3.7 Voltage range qualification

7.3.7.1 General

The system shall check initial battery voltage and shall take appropriate action, as given in 7.3.7.2 through 7.3.7.5.

7.3.7.2 Initiation of charging above specified voltage threshold

The host/pack shall not initiate charge if the battery voltage is above a threshold defined by the battery manufacturer/supplier.

7.3.7.3 Initiation of charging below voltage threshold

The system shall not initiate normal charging if the battery voltage is below a threshold defined by the battery manufacturer/supplier. In this case, the system may support a precharge function to bring the battery voltage above the required threshold. For example, a lower charge current than normally specified may be applied.

7.3.7.4 Overdischarge protection

If the host/pack incorporates a battery discharge capability, the host/pack shall ensure that the battery is not overdischarged, as defined by the battery manufacturer's specifications.

7.3.7.5 Repeated fault

The system shall disable charging and discharging of a specific battery pack, in a controlled manner pertinent to the application, if a repeated fault that could compromise the safety of operation of the system is identified.

7.4 Multi-pack systems

7.4.1 General

The considerations in 7.4.2 and 7.4.3 shall be applied to a host device with multiple battery packs.

7.4.2 Requirements

In multi-battery pack systems, the requirements in 7.3.3 shall apply to each battery pack independently.

7.4.3 Charging battery packs

The system shall not allow a battery pack to directly charge another battery pack in a multi-battery pack system without the use of an appropriate control.

7.5 Electrostatic discharge

Specific electrostatic discharge (ESD) tolerance shall be included in the system design, testing, and qualification. Test procedures described in IEC 61000-4-2 [B14] may be used.

7.6 Temperature specification

The host/pack shall incorporate temperature limitations as indicated on the Cell specification sheet. The host/pack shall take action to maintain temperature within specifications. Some examples of actions that may be taken include shutting down the system, reducing power consumption, suspending battery charging, or reducing charging current.

7.7 Battery pack qualification

The system should include a method for determining whether or not the battery pack has been qualified with the system per this standard. The system may take action if an unqualified battery is detected. Actions may include terminating charge and/or discharge, changing the charging profile, modifying system performance, and/or notifying the end user.

7.8 Mechanical considerations

7.8.1 Electrical and mechanical connections

7.8.1.1 Mating of pins

The host device and battery connections shall mate properly and be capable of good electrical contact throughout their respective product lifetimes.

7.8.1.2 Pin separation

Power and ground pins shall be sufficiently separated to minimize the possibility of an accidental short circuit between those two pins.

7.8.1.3 Pin polarity

The system shall allow the battery to be inserted only with the correct polarity.

7.8.2 Conductor ratings

The conductors and connectors shall have the proper current rating for the current load with adequate margin as determined by the system manufacturer/supplier. Multiple power pins should be used to support the current load, if required.

7.8.3 Robustness

7.8.3.1 Connector strength

The host connector to the battery shall be mechanically robust.

7.8.3.2 Performance over expected life

The host device connector shall be able to withstand the specified number of insertions and removals without damage over the expected lifetime of the system.

7.8.4 Insertion consideration for electrical circuits

“Smart batteries” may require host connector pins to have the proper mating sequence to prevent latchup in devices or damage to pack components. The ground pin or power/ground pins should be the first to make contact before all other pins.

7.8.5 Metallurgy consideration

The host device battery connector pin metallurgy shall be compatible with the battery connector pin metallurgy to minimize corrosion and resistance changes over the life of the system (see Annex J of IEC 60950-1:2005).

7.8.6 Mating force

Adequate mechanical force between the electrical contact points shall be maintained in order to minimize any fretting or other electrical degradation of the contact.

7.8.7 Shock and vibration

The host device shall withstand shock and vibration caused by normal usage and shall not propagate faults to the battery pack and cells, when they are installed in the system.

The pack shall meet the requirement of 6.12.5.3.

7.8.8 Drop test

The following drop test shall be conducted. The host is used to fully charge an installed battery pack. An independent external charger shall not be used for this test. Following the charging procedure, the drop test shall be conducted as follows. The battery pack, installed in the host, is dropped once from a height of

1000 mm (measured from the lowest point of the suspended host to the concrete) onto a concrete surface. The orientation of the resulting impacts shall be in the direction identified as the most critical for the battery pack's safety. A fixture may be used if the resulting impact is judged as technically the same as that from the freefall described herein. This procedure shall be repeated for a total of three different packs (one drop per pack).

None of these impacts from the drop test shall cause a hazard. The battery pack shall be inspected to ensure that no safety feature has been compromised, as a result of the drop test, and a battery cell has not been visibly damaged to the extent that a hazard results.

7.8.9 Foreign objects

Precautions should be taken to minimize the potential for foreign objects and/or liquids to enter the host device and defeat a safety feature either during the manufacturing process or end-user operation.

7.9 Critical testing practices

7.9.1 General

Preproduction testing and production sampling should be extensive, to confirm the design and production process. These testing procedures are not all-inclusive. Tests are designed to confirm that the hosts have the desired safety performance characteristics and are robust enough to resist abuse conditions should they arise. Testing and verification shall include all system design criteria in applicable subclauses of Clause 7.

7.9.2 Qualification of new host device designs

New host device designs shall pass specified tests identified by the manufacturer/supplier before qualification as a production host. Use manufacturer/supplier specifications or documentation to ensure control of this criterion or process.

7.9.3 Ongoing testing and verification of production host devices

Production host devices shall pass the qualification tests at intervals specified by the manufacturer/supplier to maintain compliance with the internal specification of the manufacturer/supplier. The manufacturer/supplier specifications and documentation shall be made available at regular intervals, or by request, to verify control of this criterion or process. Follow documentation requirements consistent with 11.2.

8. Adapters

8.1 AC/DC adapter, DC/DC adapter considerations

8.1.1 General

This clause includes all power adaptors that provide the energy for battery charging, but do not directly charge the battery. Adaptors provide dc input to a host charging device. Examples include linear power supplies, switch-mode power supplies, vehicular power adaptors, and auxiliary power sources (rechargeable and non-rechargeable).

8.1.2 Adapter requirements

The adapter shall meet the input requirements of the supported host charging device.

8.1.3 Adapter and safety features

The adapter shall not disable or degrade the safety features of the supported host device. The device interface shall prevent reverse polarity connection.

8.1.4 Adapter electrostatic discharge requirements

Specific electrostatic discharge (ESD) tolerance shall be included in the charging system design, testing, and qualification. Test procedures described in IEC 61000-4-2 [B14] may be used.

8.1.5 Adapter-charger interface

8.1.5.1 General

The adaptor-charger interface shall meet the safety requirements or regulations in 8.1.5.2 through 8.1.5.8.

8.1.5.2 Mating of adapter and charger

The adaptor and charger connections shall mate properly and be capable of good electrical contact throughout their respective useful lives.

8.1.5.3 Separation of pins

Power and ground pins shall be sufficiently separated to minimize the possibility of an accidental short circuit between those two pins and shall be polarized to ensure that the connection can only be made with the proper polarity.

8.1.5.4 Electrical compliance

Adaptors that are powered by ac mains shall comply with all electrical safety requirements of the country of destination. Compliance to this requirement may be shown through the use of standards such as IEC 60950-1:2005.

8.1.5.5 Current ratings

The conductors and connectors shall have the proper current rating for the current load with adequate margin as determined by the adaptor manufacturer/supplier. Multiple power pins should be used to support the current load if required.

8.1.5.6 Pin metallurgy

The adaptor connector pin metallurgy shall be compatible with the charger connector pin metallurgy to minimize corrosion and resistance changes over the life of the system. (See Annex J of IEC 60950-1:2005.)

8.1.5.7 Adapter-charger reliability

The adaptor-charger connector shall be able to withstand insertions and removals without damage over the expected lifetime of the adaptor.

8.1.5.8 Shock and vibration effects

The adaptor shall withstand shock and vibration caused by normal usage and shall not propagate faults to the battery pack and cells, when they are installed in the system.

8.1.6 Adapter and foreign objects

Precautions shall be taken to minimize the potential for foreign objects and/or liquids to enter the adaptor and cause a short circuit either during the manufacturing process or end-user operation.

8.1.7 Adaptor marking and traceability requirements

Each manufacturer/supplier shall have a traceability plan and each adaptor shall carry markings of the production lot and/or date code on the label.

8.2 Charger considerations [ac/dc charger, dc/dc charger (provides charge control directly to battery)]

This subclause includes all charging devices external to the host that directly charge the battery. Examples include desktop chargers and smart power supplies. If not otherwise specified, the responsibility for defining specific charger design requirements is incumbent upon the charger manufacturer. Furthermore, the charger manufacturer shall comply with the battery pack manufacturer's specifications for all supported batteries.

Chargers shall meet the requirements of Clause 7 and 8.1.

8.3 Critical testing practices

8.3.1 General

Preproduction testing and production sampling to confirm the design and production process should be extensive. These testing procedures are not all-inclusive. Tests are designed to confirm that the adapters have the desired safety performance characteristics and are robust enough to resist abuse conditions should they arise. Testing and verification shall include all system design criteria in 8.1 and 8.2. (See Annex A for suggested methods to address specific system functions and attributes.)

8.3.2 Qualification of new adapter designs

New adapter designs shall pass specified tests identified by the host manufacturer/supplier before qualification as a production host. Use host manufacturer/supplier specifications or documentation to ensure control of this criterion or process (see Table 1).

8.3.3 Ongoing testing and verification of production adapters

Periodic verification tests of the production adapter shall be performed at intervals specified by the manufacturer/supplier to ensure compliance with the internal specification of the manufacturer/supplier. The manufacturer/supplier specifications and documentation shall be made available at regular intervals, or by request, to verify control of this criterion or process. Follow documentation requirements consistent with 11.2.

9. Total system reliability considerations

9.1 General

This clause includes recommended information to be communicated to the end user and methods to identify and explain end-user responsibility to facilitate a reliable end-user experience. Such information may be

communicated via the owner's manual, printed labels for the host device and battery pack, host device messages, and help files as the manufacturer determines to be appropriate.

Figure 10 shows "the system," a conceptual diagram of a mobile computing device and its end user. Examples of functions of each subsystem component are also shown. The interaction between various parts of the system is also shown.

9.2 Information to be communicated to the end user

9.2.1 General

The end user shares several areas of responsibility for the total rechargeable system reliability. The system design analysis should state the areas of responsibility in terms of Figure 10.

The following information, or equivalent statements, shall be made available to the end user through one or more of the following means, as appropriate: printed on the label for the battery, printed on the label for host device, and/or printed in the owner's manual, and/or posted in a help file or on an Internet Web site.

Annex B of IEC 62133:2002 may be consulted for more information regarding recommendations to the end user.

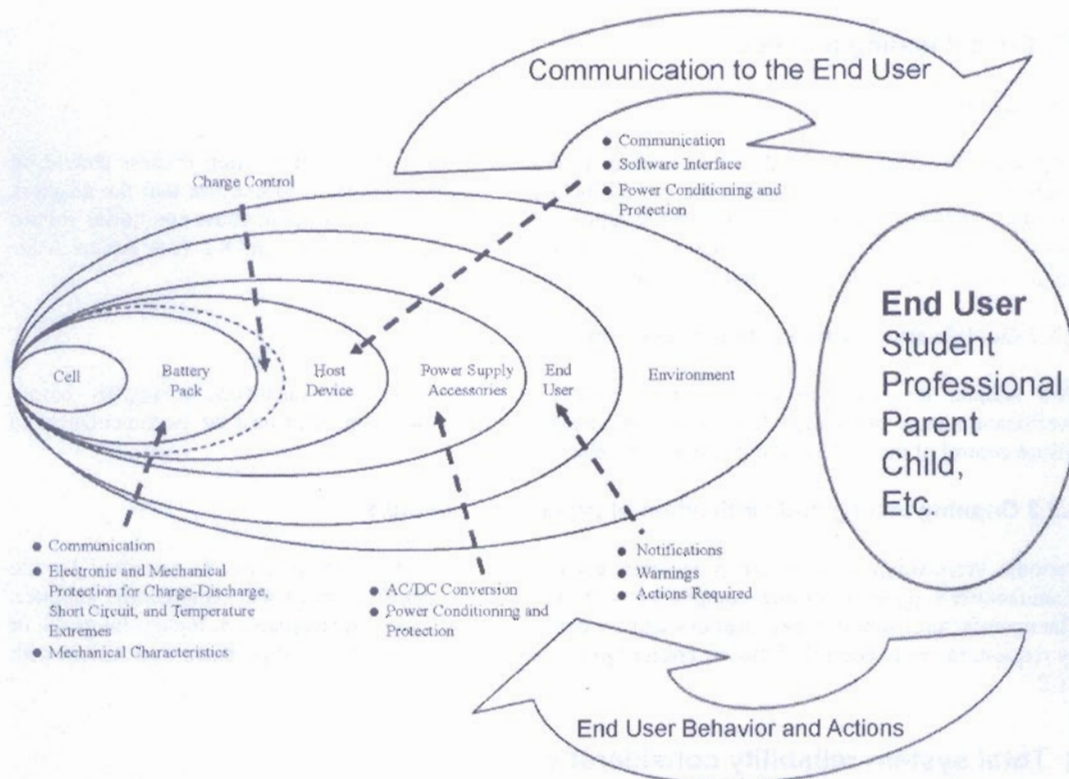


Figure 10—Conceptual diagram of a mobile computing device and its end user.
Examples of functions for each subsystem component are shown

9.2.2 Mechanical aspects

Do not disassemble or open, crush, bend or deform, puncture, or shred.

9.2.3 Proper handling

Do not modify or remanufacture, attempt to insert foreign objects into the battery, immerse or expose to water or other liquids, or expose to excessive heat, fire, or other hazard.

9.2.4 Battery usage

Only use the battery in the system for which it was specified.

9.2.5 Charging considerations

Only use the battery with a charging system that has been qualified with the system per this standard. Use of an unqualified battery or charger may present a risk of fire, explosion, leakage, or other hazard.

9.2.6 Electrical considerations

Do not short-circuit a battery or allow metallic or conductive objects to contact the battery terminals.

9.2.7 Replacement batteries

Replace the battery only with another battery that has been qualified with the system per this standard. Use of an unqualified battery may present a risk of fire, explosion, leakage, or other hazard.

9.2.8 Disposal

Promptly dispose of used batteries in accordance with local regulations.

9.2.9 Unsupervised usage

Battery usage by children should be supervised.

9.2.10 Security

Follow the explanation of a security implementation per 10.3.1.

9.2.11 Mechanical aspects

Avoid dropping the host or battery. If the host or battery is dropped, especially on a hard surface, and the end user suspects damage, take it to a service center for inspection.

9.2.12 Improper usage

Improper battery use may result in a fire, explosion, leakage, or other hazard.

9.2.13 Care and handling

Storage and operating conditions, including temperature, shall be specified.

9.3 End-user alerts

9.3.1 General

The following indications, notifications, and dialogue/messages of 9.3.2 through 9.3.8, at the system level, or an equivalent statement should be displayed along with recommended actions, as appropriate.

9.3.2 Battery status

The manufacturer may provide information on battery status.

9.3.3 Temperature alerts

The manufacturer may provide information on abnormal battery temperature alert.

9.3.4 Voltage alerts

The manufacturer may provide information on abnormal host device and/or battery dc input voltage alert.

9.3.5 Current alerts

The manufacturer may provide information on abnormal current draw alert.

9.3.6 Communication alert

The manufacturer may provide information on battery communication fail/time-out alert.

9.3.7 Incompatible battery alert

The manufacturer may provide information on incompatible battery alert.

9.3.8 Malfunction alert

The manufacturer may provide information on alert for other malfunctions that may lead to hazards.

9.4 Recommended communication to end user

9.4.1 General

The information in 9.4.2.1, 9.4.2.2, and 9.4.2.3 should be provided to the end user.

9.4.2 Advisory to end user

9.4.2.1 Warning on electrolyte leakage

In the event of leaking liquid, discontinue use of the battery, and do not allow the liquid to come in contact with the skin or eyes. If contact has been made, wash the affected area with large amounts of water and seek medical advice.

9.4.2.2 Medical assistance advisory

Seek medical advice immediately if needed.

9.4.2.3 Action in event of hazard

Communicate the appropriate steps to be taken if a hazard occurs.

9.5 Marking and labeling

Recognized international symbols may be used in place of text where appropriate. The manufacturer/supplier may also consult other relevant industry standards given in Clause 2. Additional information may be provided as appropriate, such as ISO 3864-1:2002 [B21].

10. System security considerations

10.1 General

This clause provides procedures to authenticate the compatibility of batteries and/or other subsystems for use with specific systems. Use of incompatible subsystems could potentially create a hazard. This clause suggests various methods for verification, but the final decisions are left to the manufacturer/supplier.

10.2 Purpose of authentication

The purpose of implementing authentication mechanisms in a system is to prevent or restrict the use of incompatible or counterfeit batteries. Authentication mechanisms do not specifically prohibit the use of compatible third-party accessories but may restrict their functionality with the mobile computing device.

10.3 Method of authentication

10.3.1 Host and battery authentication

There shall be a method of authentication that ensures compatibility between a specific host device and the battery. Authentication method should be active, but may be passive as defined in Clause 3.

10.3.2 Implementation by manufacturer/supplier

There are multiple methods of implementing authentication in a system. The specific method of authentication to be implemented is left to the discretion of the system manufacturer/supplier.

10.3.3 Authentication of accessories

The use of authentication mechanisms, described in this clause, should also be considered for other external accessories such as charging power sources, charging docks/cradles, USB interface devices, etc.

10.4 Supply chain security

10.4.1 Ensuring supply chain security

The manufacturers/suppliers shall be responsible for ensuring that their products, subsystems, or components (security devices, cells, etc.) do not enter the supply chain inappropriately and shall be responsible for setting up a process to ascertain that supply chain security is fulfilled by periodic audits.

10.4.2 Avoiding defective parts

The manufacturers/suppliers shall be responsible for ensuring that their products, subsystems, or components that have been found defective do not enter the supply chain inappropriately and shall be responsible for setting up a process to ascertain that the process of 10.4.1 is fulfilled by periodic audits.

10.5 Battery pack identification

The manufacturer shall have means of identification within a battery pack to allow verification by the manufacturer of the battery pack and cells. Examples of these methods include, but are not limited to, design features such as chemical or dye tags incorporated in the physical structure of the battery pack housing, non-flammable labeling, imprinted cell enclosures, or some other internal means of identifying the cell/pack source if the external housing is destroyed.

11. Quality system requirements

11.1 General

This Clause 11, Quality system requirements, and all of its subclauses, apply to the manufacturers/suppliers, themselves, of the cell, pack, host, and adaptor, as follows.

The manufacturer/supplier of the cell and/or the pack shall be responsible for obtaining and maintaining certification to the ISO 9001, Quality Management System, and defining and documenting the safety critical variables for the products and processes related to the cell and/or the pack, respectively (subclauses 11.2 and 11.3).

The manufacturer/supplier of the host and/or the adaptor shall be responsible for defining and documenting the safety critical variables for the products and processes related to the host and/or the adaptor, respectively (subclauses 11.2 and 11.3).

Likewise, the manufacturer/supplier of the cell, pack, host, and adaptor, respectively, shall also be responsible for implementing subclauses 11.4 (Process capability), 11.5 (Process stability), and 11.6 (Control of safety critical variables) of this standard, for the cell, pack, host, and/or adaptor technology(ies) that they, themselves, manufacture and/or supply.

11.2 Quality system certification and process control

The manufacturer/supplier, themselves, shall obtain and maintain certification to the ISO 9001, Quality Management System. This clause presents the requirements for a quality system certification and process control.

11.3 Definition of the safety critical variables

The manufacturer/supplier, themselves, shall be responsible for defining and documenting the safety critical variables for both products and processes.

11.4 Determination of critical measurement process capability

The manufacturer/supplier, themselves, shall assess and document measurement process capability for critical measurement processes. The assessment should include a description of the required capability to

make the intended measurement, the data showing the repeatability and reproducibility of measurements, and the records of the precision and calibration of the measurement equipment.

11.5 Determination and verification of process stability

The manufacturer/supplier, themselves, shall determine and verify that safety critical processes are stable over time. Process stability is defined as the removal of all special cause variation such that the process output is statistically predictable. This is achieved by using statistical process control (SPC), which is process monitoring and analysis using appropriate control charts with industry accepted statistical control tests as defined in AIAG SPC-3, Statistical Process Quality Control, Second Edition, or ANSI/ASQ 9002, Quality Management Systems Requirements, or equivalent.

11.6 Manufacturing control of safety critical variables

The manufacturer/supplier, themselves, shall:

- a) Set objectives and document the plan of those process parameters in which the manufacturer/supplier requires SPC
- b) Document and maintain processes, limits, and resources specific to the process parameters requiring SPC
- c) Maintain records to provide evidence that the specific controlled process parameters are carried out to the established plan and processes
- d) Document the action taken should item a), item b), and/or item c) (in subclause 11.6) be out of control.

Annex A

(informative)

FMEA techniques

A.1 General

This annex is designed to illustrate FMEA techniques and the procedures that a manufacturer/supplier uses to arrive at a complete system analysis to ensure their particular design minimizes the risk of hazards that may occur during intended use and reasonably foreseeable misuse.

A.1.1 Example 1

FMEA 2 (pack) identifies a control scheme distributed over the pack and host device for overcurrent potentially caused by the pack short circuit due to a connector contacting an external metal object, such as when packed in a mobile computing device bag with a metal pen. FMEA 4 identifies the following end-user responsibilities: Do not allow the connector to come in contact with any metal objects. FMEA 4 also identifies the following producer responsibilities: Pack has circuit and/or mechanical design to protect against external short circuit. Reliable total system operation requires a label or other notification for the end user as follows: Do not allow the connector to come in contact with any metal objects.

A.1.2 Example 2

The manufacturer/supplier conducts FMEAs 1, 2, 3, and 4 to determine whether or not protection circuits are required to minimize the risk of hazards that may occur as a result of two faults in reasonably foreseeable misuse. The manufacturer/supplier determines the best location(s) for redundant protection circuits. Building on Example 1, the manufacturer/supplier implements a mechanical protection device to protect against external pack short circuit. This mechanical protection device passes all in-spec reliability and drop tests. However, the manufacturer's/supplier's thorough FMEA analysis shows that the mechanical protection device may fail when subject to a common scenario of dropping the mobile computing device to the floor or stuffing the mobile computing device in a briefcase (Fault 1: Broken connector barrier). In this event, a second protection method shall be employed, such as an overcurrent protection (OCP) circuit. However, if the OCP fails to operate due to a manufacturing defect (Fault 2), then the cell level short-circuit protection could still provide protection against a potential hazard from the two faults listed. (One fault is a broken connector from reasonably foreseeable misuse. The second fault is a circuit failure caused by a manufacturing defect.)

A.1.3 Example 3

The charging system consists of an ac/dc power supply with a 6 V output, a charge control circuit [control and metal-oxide-semiconductor field-effect transistor (MOSFET)] in the host device, a single overvoltage protection circuit in the battery pack (control IC and MOSFET), and a single cell with a maximum voltage of 4.2 V. During the FMEA 4, the manufacturer/supplier considers a situation involving two independent faults: a short circuit in the host device charge control FET (Fault 1) and a short in the battery overvoltage FET (Fault 2). In this situation, the 6 V power supply output would be passed directly to the cell stack. The manufacturer/supplier knows that charging the cells to 6 V may lead to a hazard. To resolve this situation, a second overvoltage circuit is added to the battery pack. With this design, if the two faults described in this subclause occur, the second battery overvoltage circuit isolates the pack from the 6 V power supply.

A.1.4 A typical procedure for design analysis—FMEA

FMEA consists of a detailed engineering examination of the design before it is put into production to determine the effect of failure of a component or a subsystem on the host device.

FMEA is a document produced to identify failure modes and their effects in new designs. All failure modes are ranked and weighted by risk priority number (RPN), so that they may be prioritized and corrected.

Essential questions to ask in the FMEA are as follows:

- What elements of the design are most likely to produce defects?
- How can the defects be effectively eliminated or mitigated?
- Would your customer agree with the assignment of risk?

An example of a FMEA is shown in Figure A.1.

Once constructed, the FMEA ranks RPNs, and assignments are made to develop and review changes to mitigate or eliminate the failure effect. The RPN is a number calculated by multiplying severity, occurrence likelihood, and likelihood of not detecting the fault in a FMEA analysis. The scale is typically one through five with five being highest and one being lowest.

Some failure effects may be so low in ranking that they are not corrected.

The following bibliographic references provide additional information on conducting FMEA: Potential Failure Mode Effects and Analysis [B1], *Guidelines for Failure Modes and Effects Analysis (FMEA) for Medical Devices* [B7], *The Basics of FMEA* [B23], SAE J1739-2002 [B25], *Failure Mode and Effect Analysis: FMEA from Theory to Execution* [B28], and *Process Hazards Analysis* [B29].

Product name	Prepared by:	Page ____ of ____
Responsible	FEMA date (orig) _____ (Rev) _____	

Design function	Potential failure mode	Potential failure effects	SEV	Potential causes of failure	OC	Detection method	DET	RPN	Recommended actions	Resp.
Component, footprint design, assembly, process, engineering	Insufficient solder joints on SMT component	Motherboard failure of assembly test	4	Incorrect pad size, clogged stencil aperture	2	In-circuit test, visual inspection	2	16	Evaluate and correct pad size and stencil aperture size, modify stencil cleaning procedure	
								0		

Figure A.1—Design of potential FMEA

Annex B

(informative)

System analysis considering two faults

B.1 Why two faults should be considered in a system analysis

Protection mechanisms are intended to prevent specific failures from creating hazards, for example, a charge control circuit prevents the battery voltage from exceeding a specified value. Occasionally, a fault occurs in a protection mechanism that prevents its proper operation. Since the risk of a hazard is related to the probability of the fault occurrence, a robust design is desirable. While the probability of fault occurrence in a properly designed protection mechanism is low, it is generally not zero. Many times, it is difficult to reduce the fault probability of a single protection mechanism sufficiently to reach the desired risk level. Thus, redundant protection mechanisms should be used to achieve the goal.

If the multiple protection mechanisms are designed into the system, a hazard cannot occur unless all mechanisms simultaneously fail. It is very unlikely that two independent protection mechanisms will fail simultaneously. In fact, the probability that simultaneous failures will occur is simply the mathematical product of the predicted failure rates of the two independent protection mechanisms. If the risk level needs to be lowered further, a third protection mechanism may be necessary in the system. Thus, a careful system analysis is required where low probabilities of failure are desired.

B.2 Factors that may induce faults in a system

B.2.1 General

Figure B.1 shows various stress factors that may induce faults in a system. These factors may act alone or in combination with other factors to induce failures in protection mechanisms. Such a diagram may be useful in considering the interaction of stress factors on the system so that all possible faults are properly evaluated in a DFMEA.

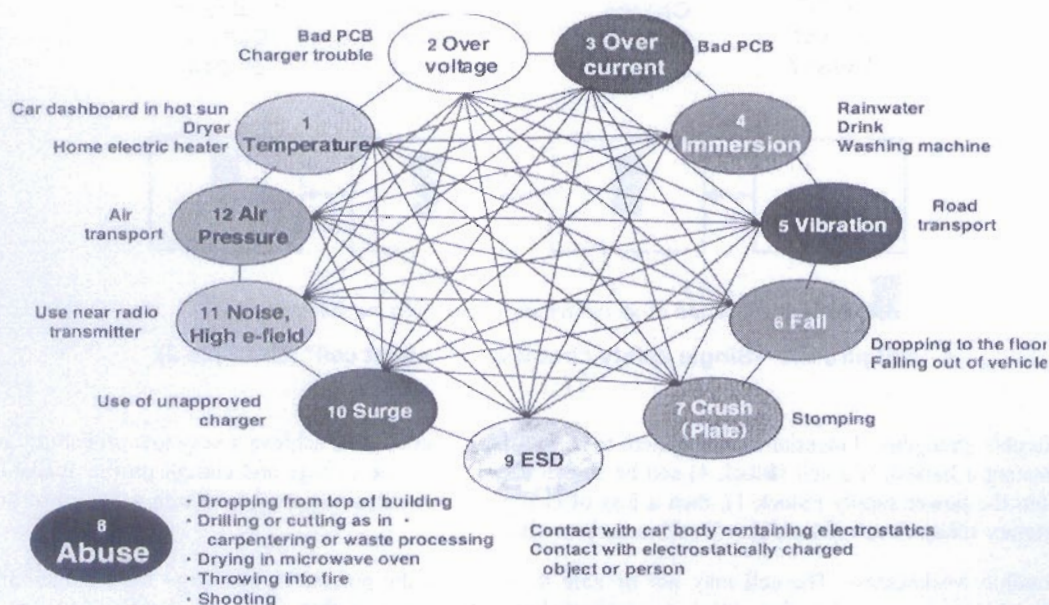


Figure B.1—Stress factors that may induce faults

B.2.2 Designs for redundant protection against battery overcharge

There are many different methods to prevent battery overcharge, but the generic examples shown in Figure B.2, Figure B.3, and Figure B.4 demonstrate how redundant protection schemes can be distributed in the overall system. The manufacturer/supplier can then select an approach to meet the goals established for their product, including minimizing the risk of overcharge to an acceptable level. Most charging system designs will be similar to one of the three examples in Figure B.2, Figure B.3, and Figure B.4.

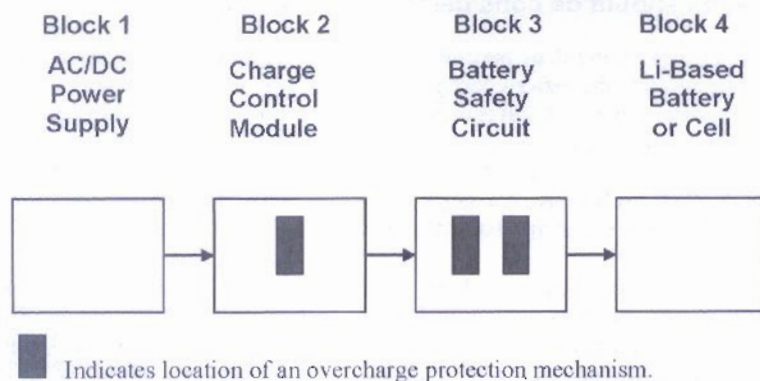


Figure B.2—Redundant protection circuits in battery (Example 1)

Possible strengths—Potential for the system to be two-fault tolerant, and achieve a very low probability of creating a hazard.

Possible weaknesses—Redundant battery safety circuits in Block 3 may not be truly independent, or one of the mechanisms may not protect against overcharge in expected situations.

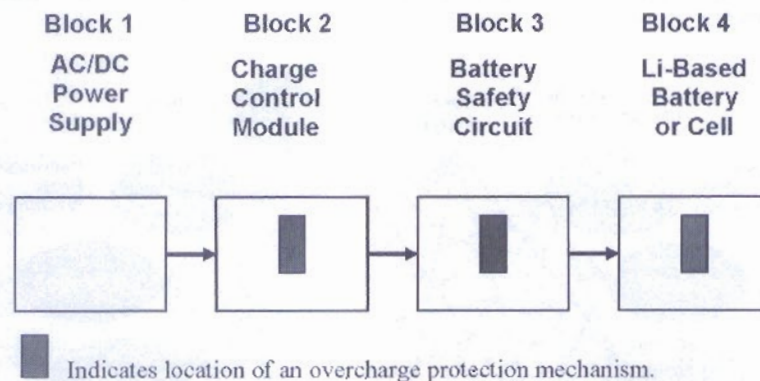


Figure B.3—Single safety circuit with “robust cell” (Example 2)

Possible strengths—Potential for the system to be two-fault tolerant, and achieve a very low probability of creating a hazard. If a cell (Block 4) can be shown to withstand the voltage and current profile available from the power supply (Block 1), then a loss of charge control (Block 2) combined with a failure of the primary safety circuit (Block 3) will still not create a hazard.

Possible weaknesses—The cell may not be able to withstand the potential overcharge from commonly available power supplies that could be connected to the system. In that case, the charging system is effectively the same as Example 3 shown in Figure B.4.

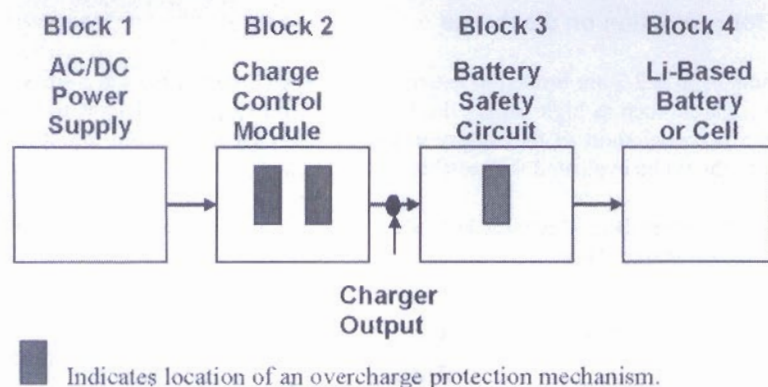


Figure B.4—Redundant charge control in host (Example 3)

Possible strengths—Potential to be two-fault tolerant and achieve a very low probability of system failure. If the charge control device (Block 2) can be designed to sufficiently restrict its output voltage and current under single-fault conditions to the “safe” region of the cell, then two faults (one fault in battery safety circuit and one in the charge control module) will not produce a hazard. The cell (Block 4) should be shown to withstand the voltage and current profile available from the power supply (Block 1), in order for the loss of charge control (Block 2) not to produce a hazard.

Possible weaknesses—If the battery is placed in a third-party charger rather than the normal host charger control device, the risk of a hazard may be the same as Example 4, which is shown in Figure B.5.

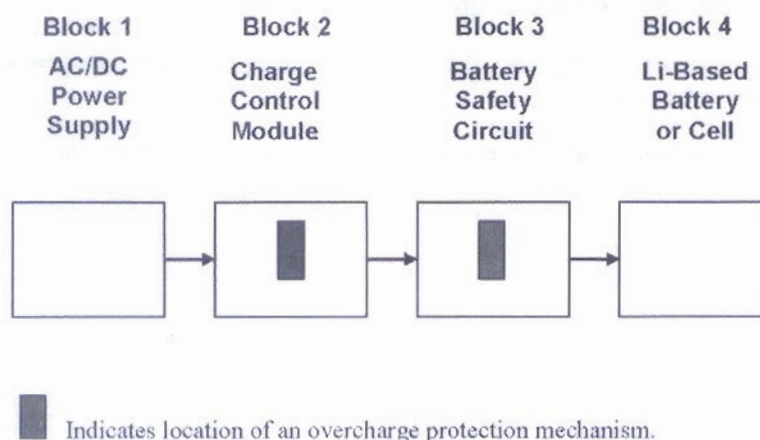


Figure B.5—Single fault tolerant design (Example 4)

Possible strengths—May be able to achieve low probability of system failure with reduced size and complexity.

Possible weaknesses—Single fault tolerant. Requires a thorough DFMEA and careful estimate of the probability of failure of both protection mechanisms in order to meet goals on overall system protection.

B.2.3 Designs for protection on discharge

Although the examples in B.2.2 are limited to battery overcharge concerns, the same approach can be used to consider other hazards, such as high battery discharge rates from a potential short in the host device, or overheating from a potential short of the battery terminals when separated from the host. All reasonably foreseeable hazards should be evaluated for possible risk mitigation.

Example 5, shown in Figure B.6, illustrates how the block diagram approach can be applied to consider potential faults in the discharge mode.

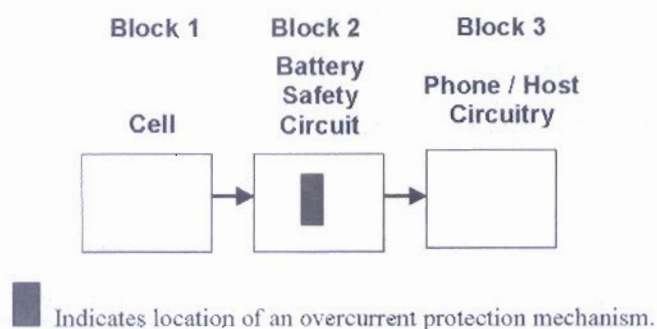


Figure B.6—Discharge fault design (Example 5)

B.3 Analysis tools for system design

The block diagram approach in B.2.2 and B.2.3 is useful for considering the hazards that may result from one or more failures in the system.

Table B.1 shows one implementation of how this method can be used to summarize the results of a system-level DFMEA.

Table B.1—Summary of a system-level DFMEA for battery overcharge

Example	System fault(s) considered	Effect on system	Additional risk mitigation
1a	Charge control is faulty and continues to charge battery beyond the desired termination voltage.	The primary safety circuit in the battery protects the cell from overcharge.	The cell should be tested and shown safe, if charged to the maximum trip voltage of the protection circuit, at the maximum charge rate of this fault mode.
1b	Both charge control is faulty and the primary battery safety circuit fails (double fault).	The back-up safety circuit in the battery protects the cell from overcharge.	The cell should be tested and shown safe, if charged to the maximum trip voltage of the protection circuit, at the maximum charge rate of this fault mode.
1c	Both battery safety circuits are nonfunctional.	Charge control still functions normally and stops at proper cell voltage.	None
2a	Charge control is faulty and continues to charge battery beyond the desired termination voltage.	The primary safety circuit in the battery protects against overcharge.	The cell should be tested and shown safe, if charged to the maximum trip voltage of the protection circuit, at the maximum charge rate of this fault mode.
2b	Both charge control is faulty and the primary battery safety circuit fails (double fault).	The cell is overcharged to the limits of the voltage and current available from the power supply.	The cell should be tested and shown safe, if charged to the maximum voltage and charge rate available from the ac or dc power supply.
3a	Charge control is faulty and continues to charge battery beyond the desired termination voltage.	The back-up charge control mechanism in the host protects the battery from overcharge.	The cell should be tested and shown safe, if charged to the maximum trip voltage of the protection circuit, at the maximum charge rate of this fault mode.
3b	Both charge control and the back-up charge control mechanisms are faulty (double fault).	The safety circuit in the battery protects against overcharge.	The cell should be tested and shown safe, if charged to the maximum trip voltage of the protection circuit, at the maximum charge rate of this fault mode.
3c	Both charge control and the battery safety circuits are faulty (double fault).	The back-up charge control mechanism in the host protects the battery from overcharge.	The cell should be tested and shown safe, if charged to the maximum trip voltage of the protection circuit, at the maximum charge rate of this fault mode.
4a	Charge control is faulty and continues to charge battery beyond the desired termination voltage.	The safety circuit in the battery protects against overcharge.	The cell should be tested and shown safe, if charged to the maximum trip voltage of the protection circuit, at the maximum charge rate of this fault mode.
4b	Both charge control is faulty and the primary battery safety circuit fails (double fault).	The cell is overcharged to the limits of the voltage and current available from the power supply.	The cell should be tested and shown safe, if charged to the maximum voltage and charge rate available from the ac or dc power supply, OR the probability of this double fault scenario needs to be sufficiently low to be considered an acceptable risk.
NOTE—The example refers to the block examples provided in B.2.2 and B.2.3.			

Annex C

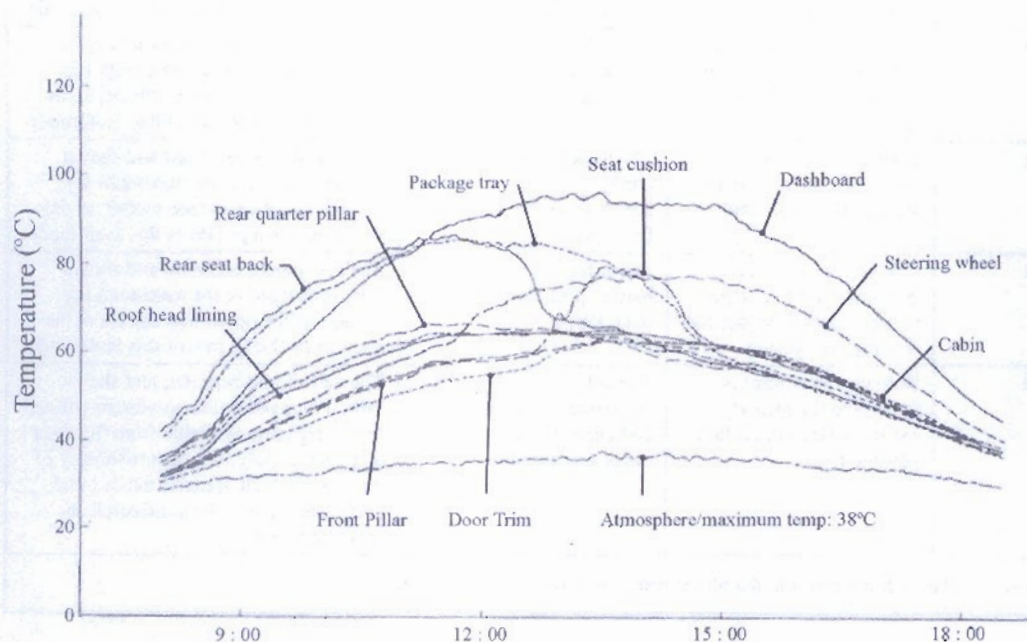
(informative)

Environmental considerations

Temperature environmental considerations

This annex includes information from a study on temperature range at various locations in automobiles. This information is provided to assist the end user of this standard when temperature is included in design analyses. This annex is intended to be a resource for the end user of the standard. This annex includes the following: temperature rise on each position in the car under clear weather (see Figure C.1); maximum temperature at each position in the car for 8 h in desert conditions under clear weather (see Figure C.2); and maximum temperature at each position in the car in Melbourne, Australia, when the maximum temperature on the day the data was taken was 40 °C (see Figure C.3).

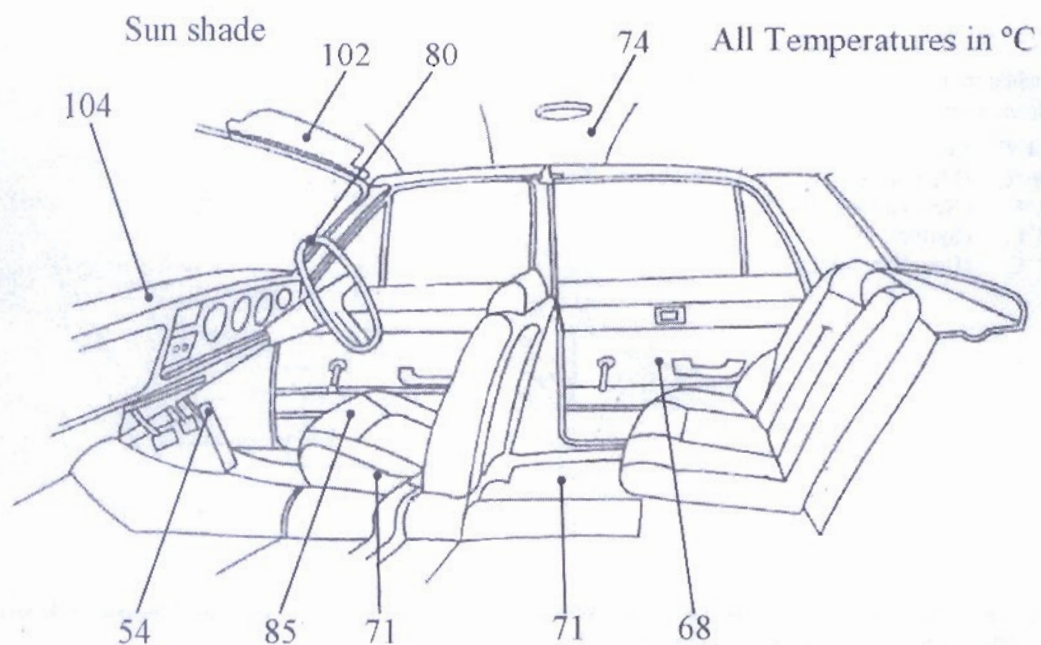
Study on temperature rise



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**Figure C.1—Temperature rise on each position in the car under clear weather
(measured by Ford)**

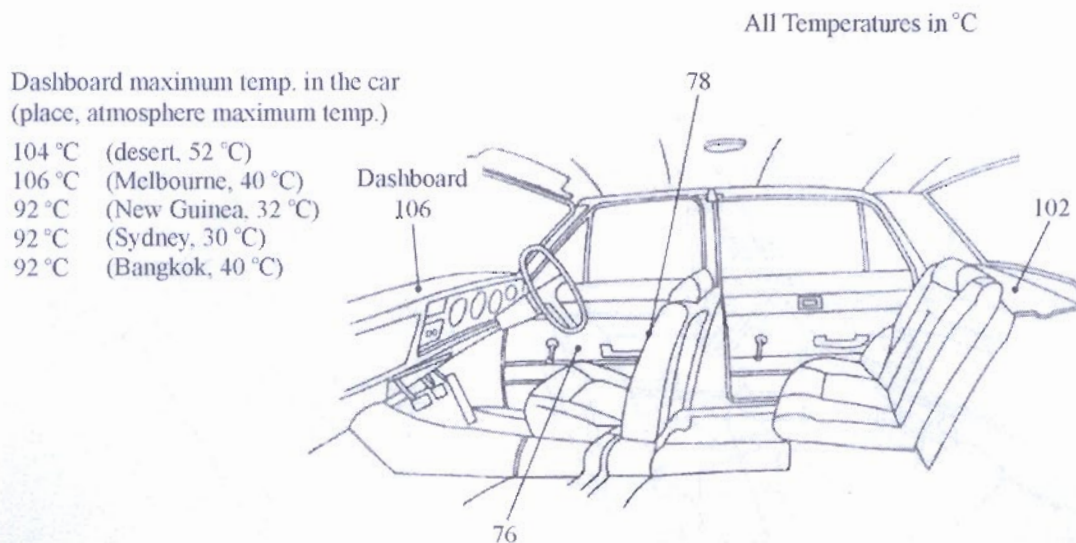
Study on temperature rise



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Figure C.2—Maximum temperature at each position in the car for 8 h in desert conditions under clear weather (outside temperature was 52 °C) (measured by Ford)

Study on temperature rise



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**Figure C.3—Maximum temperature at each position in the car in Melbourne, Australia.
Condition: Maximum temperature on the day was 40 °C**

Annex D

(informative)

Test methodologies

This annex provides information about test methodologies to evaluate a battery cell's ability to withstand internal shorts due to manufacturing, design, or external abuse. The following crush tests use force to deform cells forcing the internal components together to form shorts. Vibration and shock tests use motion to cause the contents to shift and potentially to internal short. The drop and impact tests use an external force that may or may not induce an internal short. Temperature stress causes expansion of the cell contents potentially leading to internal shorts. One of the following tests seeks to produce an internal short by introducing a particle into the windings. Every effort was made to provide impartial information about these tests. These tests provide options with advantages and disadvantages to each.

This annex addresses only published tests. At the time of writing, research underway may yield additional methods. The tests described in this annex are known as "destructive tests." The skill set required to perform these tests varies. Therefore, one is recommended to consult the publisher of these tests.

WARNING

The internal short-circuit tests described in this informative annex may be dangerous to the persons carrying out the tests. Therefore, all appropriate measures to protect personnel against possible chemical or explosion hazards should be taken. Some tests require protections specific to the test.

D.1 UL 1642-2005, Standard for Lithium Batteries

D.1.1 Impact test

Method: To drop a 9.0719 kg (20 lb) weight resting onto a metal bar, which is resting on the cell.

Purpose: To evaluate the cell's ability to withstand a blunt impact force.

Essential provisions: See UL 1642-2005, Impact Test.

Comments: This test creates a multi-layer short and compression of the cell in the area where the bar rests. This test requires basic battery testing skills. The standard outlines the dimensions and composition of the bar, in addition to the height of the drop.

D.1.2 Crush test

Method: To crush a cell between two flat plates using a 13 kN force.

Purpose: To evaluate the cell's ability to safely withstand being crushed.

Essential provisions: See UL 1642-2005, Crush Test.

Comments: This test creates a multi-layer short and compression of the cell.

D.1.3 Vibration and shock tests

Method: To subject the cell to vibration and shock.

Purpose: To see if the cell can safely withstand vibration or shock as a result of transportation.

Essential provisions: See UL 1642-2005.

Comments: A short would potentially occur if parts become displaced internally. This test requires basic battery testing skills.

D.1.4 Heating test

Scope: To subject the cell to an over-temperature.

Purpose: To see if the cell can safely withstand over-temperature conditions.

Essential provisions: See UL 1642-2005.

Comments: Internal shorting could occur in areas where insulation melts within the cell.

D.2 IEC 62133:2002, Secondary cells and batteries containing alkaline or other non-acid electrolytes—Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications

D.2.1 Crushing of cells test

Method: To crush a cell between two flat plates using a 13 kN force.

Purpose: To evaluate the cell's ability to safely withstand being crushed.

Essential provisions: See IEC 62133:2002.

Comments: This test creates a multi-layer short and compression of the cell.

D.2.2 Vibration, mechanical shock, and free-fall tests

Scope: To subject the cell to vibration, mechanical shock, or dropping.

Purpose: To see if the cell can safely withstand vibration, shock, or dropping.

Essential provisions: See IEC 62133:2002.

Comments: A short would potentially occur if parts become displaced internally.

D.2.3 Thermal abuse test

Method: To subject the cell to an over-temperature.

Purpose: To see if the cell can safely withstand over-temperature conditions.

Essential provisions: See IEC 62133:2002.

Comments: Internal shorting could occur in areas where insulation melts within the cell.

D.3 Japanese Industrial Standard (JIS) Safety Tests for Portable Lithium Ion Secondary Cells and Batteries for Use in Portable Electronic Applications, C8714-12 Nov 2007

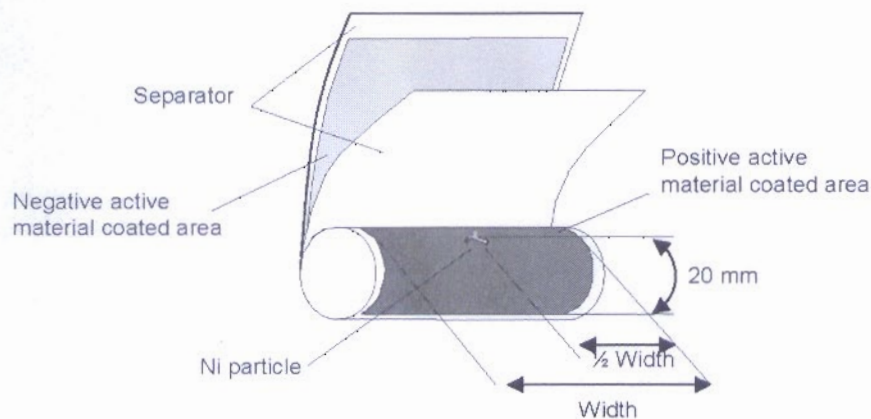
D.3.1 Forced internal short-circuit test (Version 1.0)

Method: This test provides a procedure for performing a cell internal short-circuit test, by inserting a nickel (Ni) particle of a specific size into a disassembled charged cell to simulate a cell internal short circuit that can lead to a hazard by foreign particle contamination, etc. See Figure D.1 and Figure D.2. This test is for the evaluation of the cell design of the Li-ion cells, and is not intended for polymer cells.

Purpose: To determine the battery cell's ability to safely withstand an internal short circuit between the positive and negative electrodes and, in some cases, an internal short circuit between the negative electrode and the aluminum foil of the positive electrode. Additionally, this test simulates a single-layer short circuit between the positive and negative electrodes.

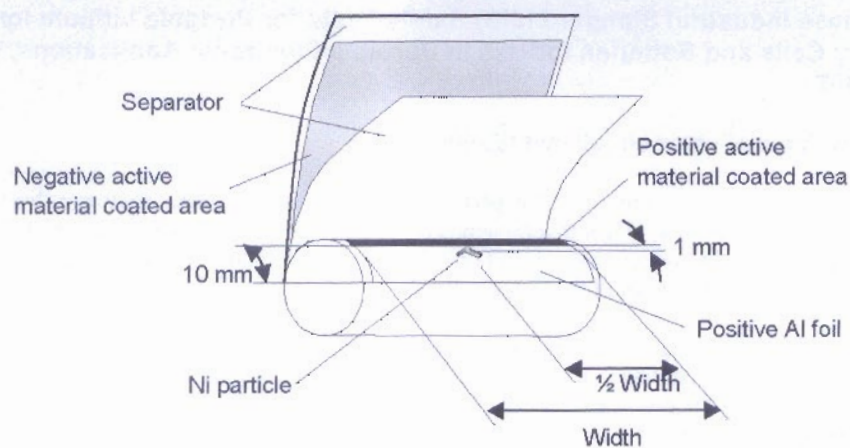
Essential provisions: This test includes a procedure for inserting and positioning the Ni particle to generate an internal short. Since the charged cells shall be disassembled to conduct this test, this test includes specifics on disassembling both cylindrical and prismatic cells. The number of samples, conditioning, charging procedures, and the exact shape of the Ni particle are included.

Comments: To conduct the cell disassembly/cell preparation prior to this test, a specialized, highly trained operator is essential. Additionally, the disassembly/cell preparation portion of this test shall be carried out in a controlled environment, such as a purged glove box.



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Figure D.1—Ni particle insertion position between positive and negative active material coated areas of a cylindrical cell



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Figure D.2—Ni particle insertion position between positive aluminum foil and negative active material coated areas of a cylindrical cell

Annex E

(normative)

Cell specification sheet

- (1.) This normative annex provides a template for communicating cell characteristics, so that:
 - a) A cell vendor provides complete information about cells.
 - b) A pack designer receives complete information about cells to ensure that cells are treated appropriately relative to operating conditions. Additionally, the pack designer receives information about cell dependencies, such as maximum charge current as a function of temperature.
- (2.) Some parameters may depend on cell usage, and therefore require information about usage models to be provided by the pack manufacturer in order to be complete. The Cell specification sheet should include information about the related usage models; additionally, an application-specific Cell specification sheet should state the usage model for which parameters are provided.
- (3.) Cell specification sheets may indicate "contact vendor for details" for those details that require other agreements about operating conditions of the cells.
- (4.) This template includes "optional" items that do not have to be completed to comply with this standard.
- (5.) TEMPLATE:

a)	Date:
b)	Manufacturer:
c)	Model number:
d)	Statement of confidentiality (optional): An example statement of confidentiality follows: "Some of the information in this Cell specification sheet is proprietary. As such this information is the property of <insert name of cell vendor>. This is information and is offered solely for the use of the recipient company, and may not be used for any purposes other than evaluation or use of the cells specified here." Optionally, a reference to a preexisting statement of confidentiality can be included.
e)	Reference to application for this Cell specification sheet (optional):

f) **Rated specifications:**

Nominal voltage

Rated capacity (defined by IEC standards as the minimum declared by the manufacturer)

Typical capacity

Test methods:

(Optional) Remarks or data regarding the likely spread of capacity over the life of a pack. If the proximity of some cells to heat sources affects the capacity spread, add remarks with comments about the likely diversion in capacity over time, assuming all cells maintain the same temperature.

g) **Case dimensions:**

(Optional) Insert image of cell here.

	Typical	Minimum	Maximum
Diameter/thickness	(Insert value)	(Insert value)	(Insert value)
Height/length	(Insert value)	(Insert value)	(Insert value)
Width (prismatic/polymer)	(Insert value)	(Insert value)	(Insert value)

This information shall explain the variations of dimensions that result from charging, discharging, and aging. Alternatively, this information shall alert the cell vendor to the maximum dimensions, which depend on usage models. Maximum dimensions are generally attained with high cycle count, high temperature, and full SOC.

h) **Case type, such as aluminum can or polymer pouch:**

i) **Identification markings:**

Cell identification markings should be readable after all reasonably foreseeable circumstances, including analysis of cells after cell or pack failure events.

Sleeve marking, if present	(Insert marking)
Can marking	(Insert marking)

j) **Weight:**

Typical	Minimum	Maximum
(Insert value)	(Insert value)	(Insert value)

k) **Chemistry:**

Anode material:	
Cathode material:	
Electrolyte (optional):	

If the information about the chemistry is restricted to that provided in a product information data sheet (PIDS), then insert the PIDS information. This protects the proprietary nature of the formula used by cell developers.

l) **Safety devices:**

Safety devices present:

	Included?
Positive temperature coefficient (PTC) device ^a	(Insert yes or no)
Current interrupt device (CID)	(Insert yes or no)
Pressure release vent	(Insert yes or no)
Other reliability design features (describe)? (optional)	(Insert yes or no)

^a The PTC operation characterization may include an impedance versus temperature curve, current carrying capability, and activation temperature (optional).

The other reliability design features may include special separator characteristics, methods to protect against thermal runaway, or any other precautions in addition to those listed above.

m) **Charging:**

Standard charge rate:	(Insert value in mA)	(Insert conditions)
Quick charge rate:	(Insert value in mA)	(Insert conditions)

The Operating region (see Figure E.1) depicts the maximum values. A margin is recommended.

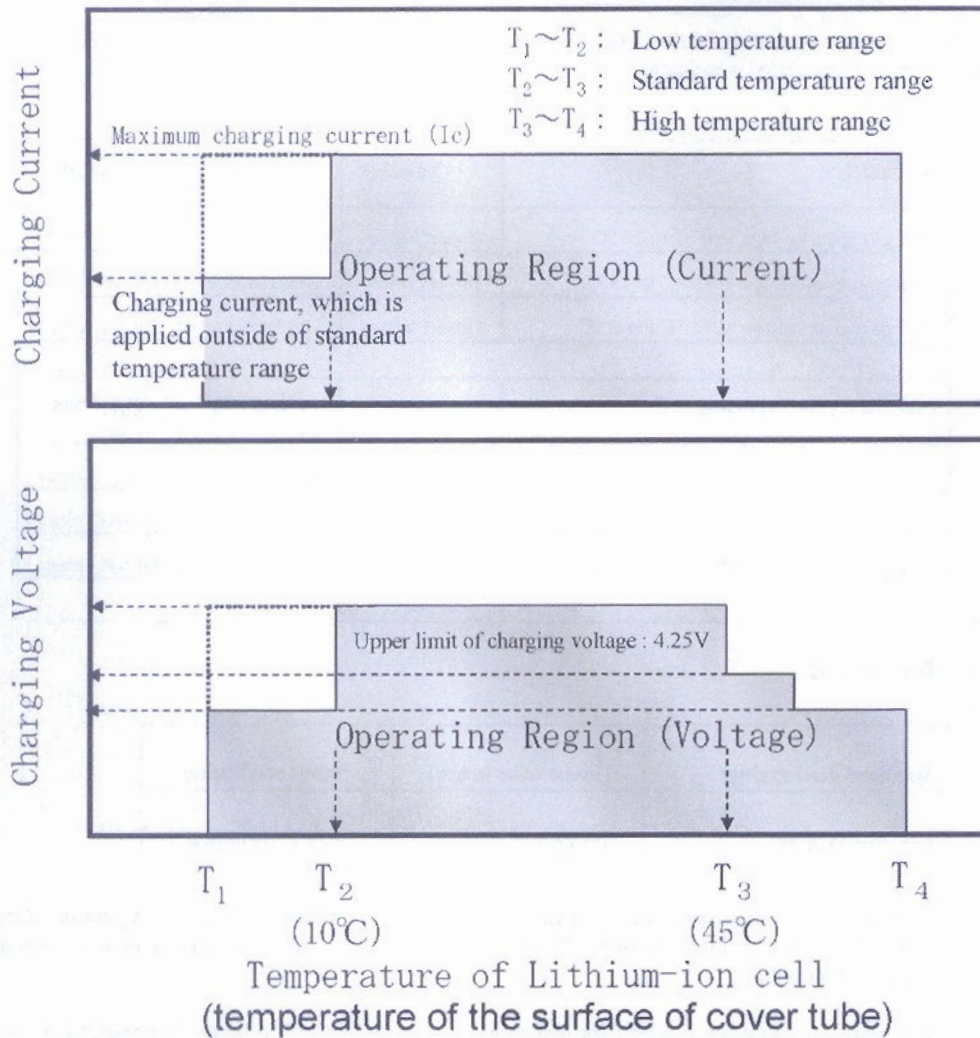
Standard charge termination voltage	(Insert value)
Maximum charge termination voltage	(Insert value)
Critical charge termination voltage	(Insert value)

Operating region for reliable operation

Battery management circuits are able to operate on more detailed models than the step function illustrated in Figure E.1. A cell vendor may provide a continuous curve to depict the safety window in Figure E.1. This may be presented in the form of a series of computations that such a battery management circuit may use to maintain the cells in the safety window at any given temperature.

If the Operating region changes as a result of cycling, this should be noted in remarks. This may be in the form of a zero-cycle diagram or another format. Optionally, a distinction should be made between the normal operating window and the boundaries for safety, either through written remarks or by inclusion in diagrams. Figure E.1 is an example of cell charging characterization. The values are for illustration purposes only.

m) Charging (*continued*):



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Figure E.1—Example of Operating region (charging)

m) **Charging (continued):**

Charge voltage cutoff:

NOTE—These values ensure that correct clamp voltages are used across a range of temperatures and take into account the changes associated with aging.

(For safety)	New	Cycle 150	Cycle 300
Charge clamp voltage at 0 °C to 10 °C	(Insert value)	(Insert value)	(Insert value)
Charge clamp voltage at 10 °C to 45 °C	(Insert value)	(Insert value)	(Insert value)
Charge clamp voltage at 45 °C to 60 °C	(Insert value)	(Insert value)	(Insert value)
(For maximum cycle life)	New	Cycle 150	Cycle 300
Charge clamp current at 0 °C to 10 °C	(Insert value)	(Insert value)	(Insert value)
Charge clamp current at 10 °C to 45 °C	(Insert value)	(Insert value)	(Insert value)
Charge clamp current at 45 °C to 60 °C	(Insert value)	(Insert value)	(Insert value)

n) **Discharging:**

Standard discharging:	(Insert value in mA)	(Insert conditions)
Fast discharging:	(insert value in mA)	(Insert conditions)

A diagram or algorithm indicating acceptable discharge rates at various temperature (see Figure E.1) may be included here. This may be repeated to depict acceptable charge rates at high cycle counts.

Information should be provided for discharge current and cutoff voltages. Information should include a normal operational envelope and safety limits.

Discharge voltage cutoff:

Assumption: The end of the discharge voltage is not temperature-dependent. If the preceding assumption is not true, outline the related dependency.

	New	Cycle 150	Cycle 300
End of discharge voltage at C/2	(Insert value)	(Insert value)	(Insert value)

o) Self-discharge; in use and in storage:

The self-discharge rate of the cell is important to correctly estimate the shelf life of battery packs that are stored in a distribution channel.

Remaining capacity (measured at C/5 and presented as percent of nominal) after specified storage period at 25 °C	Starting SOC (%)	Typical remaining capacity (%)
28 days	100	(insert value)
3 months	100	(insert value)
28 days	SOC at cell shipment which declared by cell manufacturer	(insert value)
3 months	SOC at cell shipment which declared by cell manufacturer	(insert value)

To be filled in (extra comments) (optional)

p) Undervoltage limits:

Explain here how to recover from undervoltage with a precharge. Explain at what voltage this should not be attempted. If time plays a role on whether or not a precharge should be attempted, outline that. Provide numbers to support the remarks below.

Undervoltage limits (at 25 °C)	New	Cycle 150	Cycle 300
Do not recharge			
Voltage < V1	(Insert value)	(Insert value)	(Insert value)
Elapsed time > X	(Insert value)	(Insert value)	(Insert value)
OK to recharge at C/XX			
V2 < Voltage < V1	(Insert values)	(Insert values)	(Insert values)
Elapsed precharge time < X	(Insert values)	(Insert values)	(Insert values)

q) Impedance:

Remarks (optional): Provide comments regarding impedance values that may indicate problems with the cells.

	New		Cycle 150		Cycle 300	
Impedance	100% SOC	0% SOC	100% SOC	0% SOC	100% SOC	0% SOC
Typical impedance range (mΩ) (measured @ 1 kHz, 25 °C)	(Insert value)	(Insert value)	(Insert value)	(Insert value)	(Insert value)	(Insert value)

Test method:

r) Usage limitations:

Insert information about any usage limitations. For example, "Not recommended for usage in multi-cell packs (reasons: imbalance, lack of PTC, etc.)." Insert information here about applications for which the cells are unsuitable.

s) Handling precautions:

Insert information about examples of handling precautions. For example, "Minimum bend radius for tabs on prismatics, soldering, welding locations, protecting polymer from damage, etc." A second example, "If one gets electrolyte on one's hands, follow these precautions."

t) Warranty information:

Insert warranty information here.

u) Certifications (list certifications and/or declarations of compliance):

v) **Additional safety tests that exceed those certifications listed in item f):**

(Optional) References to additional safety tests can be listed. Examples follow:

Behavior	Test method	Pass criteria
Leakage		
Vibration		
Drop		
Short circuit		
Etc.		

Annex F

(informative)

Glossary

For the purposes of this standard, the following terms and definitions apply. These and other terms within IEEE standards are found in *The Authoritative Dictionary of IEEE Standards Terms* [B17].

battery management unit: An implementation of a battery management circuit, which has been implemented as a stand-alone circuit board, typically located in the battery pack.

cause-and-effect (fishbone) diagram: A branching, skeletal diagram used to illustrate cause and effect. Main branches are typically labeled “manpower, methods, materials, and machinery.” This diagram is also known as an Ishikawa diagram.

cell leakage: The appearance of the cell electrolyte outside the contained components. Leakage is evidenced by liquid or condensed electrolyte composition external to the cell on the cell surface.

electrostatic discharge (ESD): Electrical discharges of static electricity that build up on personnel or equipment generated by interaction of dissimilar materials. The discharge may damage sensitive components and render them inoperative.

failure mode: The manner in which failure occurs, generally categorized as electrical, mechanical, thermal, or contamination. It can be associated with a defect or use outside of specifications.

failure mode and effects analysis (FMEA): A systemized group of activities to recognize and evaluate the potential failure of a product or process and its effects, identify actions that could eliminate or reduce the occurrence of the potential failure, and document the process.

fault: A physical condition that causes a device, component, or element to fail to perform in the required manner. Examples include short circuits, broken wires, intermittent connections, and software errors.

hazard: An undesirable result of one or more faults that includes a forceful rupture of the battery pack and/or projectile emission, fire or flame outside of the battery enclosure, noticeable quantity of smoke, release of toxic, corrosive, or dangerous materials in excess of recognized health and safety standards, electric shock that exceeds accepted standards, systems or components generating untouchable surfaces, and leakage of liquid outside of system enclosure.

may: The word “may” indicates a course of action permissible within the limits of the standard.

NOTE—Refer to Annex G of ISO/IEC Directives, Part 2 [B22].

open circuit voltage (OCV): The voltage at its terminals when no appreciable current is flowing (cell or battery pack).

process control: The method for keeping a process within boundaries; the act of minimizing the variation of a process.

shall: The word “shall” is used to indicate mandatory requirements strictly to be followed in order to conform to the standard.

NOTE—Equivalent definition of ISO/IEC Directives, Part 2 [B22]: Shall = is to; is required to; it is required that; has to; only....is permitted; it is necessary.

should: The word “should” is used to indicate that among several possibilities one is recommended as particularly suitable without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in a negative form) a certain course of action is depreciated but not prohibited.

NOTE—Equivalent definition of ISO/IEC Directives, Part 2 [B22]: Should = is recommended that; ought to.

smart battery system (SBS): An industry standard for managing battery systems using defined messages and message structures.¹²

¹² The SBS standard [B27] is maintained by the SBS Implementers Forum (SBS-IF) at <http://sbs-forum.org/>.

Annex G

(informative)

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¹³ AIAG publications are available from the Automotive Industry Action Group, 26200 Lahser Rd., Suite 200, Southfield, MI 48033-7100, USA (<http://www.aiag.org>).

¹⁴ ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

¹⁵ CISPR documents are available from the International Electrotechnical Commission, 3, rue de Varembe, Case Postale 131, CH 1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). They are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

¹⁶ This publication is available from the Battery Association of Japan, Kikai Shinko-Kaikan, Suite 509, 5-8, Shibakoen 3-chome, Minato-ku, Tokyo 105-0011, Japan (<http://www.baj.or.jp>).

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¹⁹ IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

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²⁴ The SBS standard is maintained by the SBS Implementers Forum (SBS-IF) at <http://sbs-forum.org/>.

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