Li-Ion Battery Safety and Handling Guideline

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# TABLE OF CONTENTS

1.0 Purpose .............................................................................................................. 3  
2.0 Definitions........................................................................................................... 3  
3.0 Responsibilities................................................................................................. 3  
4.0 Cell Handling Procedures.................................................................................. 4  
5.0 Cell Storage....................................................................................................... 5  
6.0 Battery Packs.................................................................................................... 5  
6.1 Cell Matching and Combination....................................................................... 5  
6.2 Battery Pack Design........................................................................................ 5  
6.3 Hazard Analysis............................................................................................... 6  
6.4 Battery Pack Fabrication.................................................................................. 7  
7.0 Shipment........................................................................................................... 8  
8.0 Emergency Procedures..................................................................................... 8  
8.1 Releases from Cells (Vented, Leaked or Exploded)......................................... 8  
8.2 Handling a Hot Cell ....................................................................................... 8  
9.0 First Aid Procedures........................................................................................ 9  
10.0 Waste Management....................................................................................... 9
1.0 PURPOSE

The intent of this guideline is to provide the users of lithium ion batteries with guidance to facilitate the safe handling of battery packs and cells under normal and emergency conditions.

2.0 DEFINITIONS

Secondary or rechargeable lithium ion cells
- Rechargeable secondary cells utilize lithium ions that are intercalated into graphite, lithium metal oxides, and/or lithium salts. There is no metallic lithium in a lithium ion battery.

Cell
- A single battery without external modification.

Battery Pack
- An assembly of cells that are connected in series and/or parallel. Each battery pack contains only one cell model regardless of the number of cells used, and is protected from external conditions by a Battery Management System. Voltage and Capacity of a battery pack is directly proportional to the number and configuration of cells.

3.0 RESPONSIBILITIES

Engineers/Designers/Manufacturing Operations

* Implementation of all applicable provisions of this guideline.

* Obtain and review the battery manufacturers Material Safety Data Sheet (MSDS), Technical Specification sheet(s) and/or other available documentation prior to the design and use of battery packs. Perform hazard analysis (a.k.a. risk assessment) to understand the various failure modes and hazards associated with the proposed configuration and type(s) and number of batteries used.

* Based on a hazard analysis, incorporate appropriate safety-related design and testing criteria into battery pack and device design, with the design objective of increasing the safety margin during the battery pack life cycle. Ensure safety-related requirements are incorporated into design.

* Ensure that written standard operating procedures (SOPs) for Lithium Ion battery pack production and installation are developed that include mechanisms to mitigate possible battery failures that can occur during: assembly, deployment, data acquisition, transportation, storage, and disassembly/disposal.

* Ensure that acceptance and quality-control procedures include verification of safety design features.
4.0 CELL HANDLING PROCEDURES

Inadvertent short circuits are the major cause of failures for Lithium Ion (Secondary) cells. Problems associated with shorting as well as other hazardous conditions can be reduced by observing the following guidelines (Please note that these are general recommendations):

* Written work instructions or checklists should be generated for assembly and testing procedures.
* Wear safety glasses whenever handling batteries.
* Remove all exposed jewelry and metal items such as rings, wristwatches, pendants, etc., that could come in contact with the battery terminals.
* All dented cells or batteries with dented cells should be disposed, regardless of electrolyte leakage. Denting of sides or ends increases the likelihood of developing an internal short circuit at a later time.
* Cover all metal work surfaces with an insulating material. Work areas should be clean and free of sharp objects that could puncture the insulating sleeve on each cell.
* If cells are removed from their original packages for inspection, they should be arranged to preclude shorting. Do not stack or scatter the cells. They should be placed in non-conductive carrying trays with individual compartments for each cell.
* Cells should be transported in non-conductive carrying trays. This will reduce the chances of cells being dropped, causing shorting or other physical damage.
* All inspection tools (including calipers, rulers, etc.) should be made from, or covered with, a non-conductive material.
* Cells should not be forced into battery holders or other types of housings. This could deform the cell casing causing an internal short circuit. Furthermore, the terminal cap could be crushed putting internal component and structure at risk. This could result in a cell venting. Check for proper fit before inserting the cells into any type of housing.
* Excessive force should not be used to free a cell or battery lodged inside the housing.

Cells and/or packs should not be exposed to any voltage sources other than those that meet the exact criteria identified by the pack/cell specification. Secondary cells should be charged only according to the cell or battery manufacturer’s directions, particularly with respect to maximum applied voltage.
5.0 CELL STORAGE

* Cells should be stored in their original containers.
* Lithium-Ion batteries should be stored at ~40% rated capacity. Shipments direct from the cell manufacturer will be received at this relative state of charge.
* Store the cells in a well ventilated, dry area. Optimal storage temperature should be maintained at or below room temperature of 60-75° F. Observe the manufacturers’ minimum and maximum storage temperatures.
* Store the cells in an isolated area, away from combustible materials. Store depleted cells in an area separate from fresh cells.
* Never stack heavy objects on top of boxes containing lithium batteries to preclude crushing or puncturing the cell case. Severe damage can lead to internal short circuits resulting in a cell venting or explosion.
* Do not allow excessive quantities of cells to accumulate in any storage area.

6.0 BATTERY PACKS

6.1 Cell Matching and Combination

Obtain and review the battery manufacturer’s design information for the cells to be used. It is important to know the working limits of the cells selected, so that the battery packs will meet performance requirements without undesirable reactions.

The following basic rules must be observed in pack construction:

* Always use the same model cells in series or parallel connections.
* Cells fabricated into a battery pack shall be of the same age (lot code) and history.
  - Li-ion cell lot codes that exceed one (1) year from date of manufacture shall be measured with a DMM (Digital Multi Meter) and screened to be within .010V of each other.
* Primary and secondary cells shall not be mixed together in a battery pack.
* Partially discharged cells shall not be mixed with fresh cells in a battery pack.

6.2 Battery Pack Design

The design of a battery pack can either enhance or reduce the safety characteristics of individual cells and the pack. Combinations of series and parallel configurations may cause voltage and current potentials unsafe for the individual cells in the strings. A proper BMS
(Battery Management System) shall be designed and integrated according to the cell manufacturer’s safety requirements while also considering the safety of the host device powered by the battery and related charging system.

Battery packs should be designed to avoid conditions leading to short circuiting, forced over-discharging, over-charging, overheating or other known electrical and mechanical failure conditions. Packs must also be designed to avoid conditions leading to low level current leakage paths which could lead to internal cell short circuiting. This can be accomplished by choosing proper insulating materials for use in the pack construction. It should be noted that the insulation resistance of materials decreases rapidly with increased temperature. Also, absorbed moisture reduces the insulation resistance, and moisture and humidity could have a large effect on the surface leakage of a battery and the BMS.

Pack construction materials must have good abrasion or puncture resistance in addition to having good electrical properties. For example, if circuit boards are mounted directly on top of the battery, cell terminations must be isolated from traces on the underside of the board. Solder points can have sharp protrusions that can puncture thin materials. Thick, puncture resistant insulation must be used in these areas.

Additional hazard control measures that should be considered include:

* In-line fuses should be incorporated in any li-ion pack design.
* Thermal cutoff (TCO) or resetable polymeric, positive temperature coefficient (PTC) resistors can be used to limit cell temperature rise when that rise is caused by external current flow through the protective device. Charging schemes should carefully monitor pack temperature and not violate cell capability.
* Batteries should not be encapsulated without first consulting the manufacturer.
* Battery pack construction should take into account the need for cell vents to function. There should be an minimally restricted escape path for the fumes such that pressure does not build up in the battery pack or housing. A vent mechanism should also be incorporated in rigid housings to avoid rupture or an explosion in the event of overpressure.
* Shock and vibration requirements must be considered in the design of any battery pack. All cells must be protected from excessive shock and vibration.
* In general, regulations specific to the mode of transportation intended to be used (air, land, water) may influence the battery pack design. In larger format batteries, it may be imperative to follow a modular approach.

6.3 Hazard Analysis

To increase the safety margin and decrease the failure rate, the hazard analysis process should be considered during the design phase. This can be the case for battery pack designs, where there is a possibility that a component failure could give rise to an increased
hazard. A number of different methods can be used, varying from simple analytical approaches to complex mathematical modeling. The hazard analysis method should be appropriate to the system design.

Examples of hazard analysis methods are listed below.

**Checklists:** Checklists can be used as a basic method for itemizing potential hazards or undesirable outcomes that need to be considered. Conditions of internal battery pack safety as well as likely environmental or usage case concerns should be addressed.

**Fault modes and effects analysis (FMEA):** Identification and frequency analysis of all possible fault modes within a battery pack design to determine their effects. This is typically followed by a PFMEA where Production elements are assessed for risk in constructing the battery pack design.

**Hazard and operability studies (HAZOP):** HAZOP studies examine each part of an entire system to determine how deviations from the intended function or performance can lead to undesirable outcomes.

### 6.4 Battery Pack Fabrication

Personnel assembling battery packs should comply with the following recommendations:

* Safety glasses must be worn at all times. All jewelry should be removed so that cells are not inadvertently shorted.
* Cells received from the factory should remain in their original containers until they are to be assembled into battery packs.
* Cells should not be placed on electrically conductive surfaces. All work surfaces should be constructed with non-conductive materials.
* Do not solder directly to the cell case or cell terminals. Only solder to the solder tabs welded to the case or weld terminals.
* Solder tabs that extend from the case and terminal cap should be insulated.
* Avoid cutting or piercing the insulating shrink wrap on the cells.
* Loose wires should not be stripped until it is time to install a connector. If no connector is used, wire ends should be insulated.
* Should wire trimming be necessary, only cut one wire at a time.
* All battery packs should be labeled with the appropriate warnings as required by international, federal, and local regulation.
* Operators should be aware of potential abuse to cells within a battery construction either from thermal rise, physical damage, or short circuit.
7.0 SHIPMENT

All batteries must be made safe for handling prior to packing for shipment. A written SOP should specify steps to take in preparation for shipment or transportation of each unique cell or battery pack design.

U. S. domestic transportation is regulated by the Department of Transportation (DOT). Internationally, air transportation is regulated by the International Air Transport Association (IATA) and International Civil Aviation Organization (ICAO). Maritime transport is controlled by International Maritime Organization (IMO) whose regulations are contained in the International Maritime Dangerous Goods (IMDG) Code.

Various weight limits apply to batteries, batteries with equipment, and batteries installed in equipment for all transportation methods. Pursuant to 49 CFR 173.185, all shipments of hazardous materials must comply with packaging regulations based on recommendations made by the United Nations. Fines and penalties for non-compliance can be substantial.

8.0 EMERGENCY PROCEDURES

8.1 Releases from Cells (Vented, Leaked or Exploded)

The electrolyte contained within the lithium cells can cause severe irritation to the respiratory tract, eyes and skin. In addition, violent cell venting could result in a room full of hazardous air contaminants, including corrosive or flammable vapors. All precautions should be taken to limit exposure to the electrolyte vapor. Review the MSDS or product information sheet PRIOR to working with cells, so that you are familiar with the steps to take in the event of a release.

8.2 Handling a Hot Cell or Battery Pack

* As soon as it has been determined that a hot cell situation exists, completely evacuate all personnel from the area. The area should be secured such that no unnecessary persons enter.

* If it is safe to do so before evacuating the area, quickly determine if an external short-circuit is present and remove it as quickly as possible. Note that some cell chemistries may enter a thermal runaway reaction above a certain temperature; thus, a cell may continue to gain heat and there may be a cascade to other cells.

* If it is safe to do so before evacuating the area, the cell or battery pack should be carefully put into the emergency sand container nearest the incident. Proper gloves and eye-ware
must be worn while containing/isolating the thermal event. The area should remain evacuated until the cell has cooled to room temperature.

* Because there is no metallic lithium in a lithium ion battery, ordinary extinguishing agents can be used effectively on a fire involving lithium ion batteries

* In addition to the battery itself, packaging materials, plastics, electronic components and flammable solvents may be involved in a fire.

9.0 FIRST AID PROCEDURES

In case of contact with electrolyte, gases, or combustion byproducts from a lithium ion battery release, the following first aid measures should be considered:

* EYES: Immediately flush eyes with a direct stream of water for at least 15 minutes with eyelids held open, to ensure complete irrigation of all eye and lid tissue. Get immediate medical attention.

* SKIN: Flush with cool water or get under a shower, remove contaminated garments. Continue to flush for at least 15 minutes. Get medical attention, if necessary.

* INHALATION: Move to fresh air. Monitor airway breathing and circulation. If troubled breathing, dizziness, or discomfort persists, get immediate medical attention.

10.0 WASTE MANAGEMENT

All waste management steps (collection, temporary storage, recycling, disposal, etc) for spent or waste lithium ion batteries must conform with federal, state, and local regulations.

There are a number of facilities that will recycle Lithium Ion Batteries. The Rechargeable Battery Recycling Corporation (RBRC) is an excellent source for determining a facility for cell and pack reclamation. This is the preferred disposal method of cells and battery packs.

Li-ion batteries can be incinerated if there is a large quantity and proper notification to the waste company must include clear marking of “li-ion batteries contained.” Incineration must be performed by an approved and permitted waste treatment facility that handles lithium ion batteries.

Before any type of disposal, the batteries should be discharged completely. Tape the contacts with electrical tape and package so as to prevent contacts accidentally coming together at any time.