Overview of Lithium Battery Safety
Presented by Matthew Larkin
Consultant, Battery Certification Services, TÜV SÜD Product Service
History

The lithium battery can be traced back as far as 1912 with the work of American physical chemist Gilbert Newton Lewis.

Non-rechargeable (Primary) lithium batteries became commercial in the 1970’s.

20 years later re-chargeable (Secondary) lithium-ion batteries became commercially available.

This was primarily through the work of John Goodenough and his contemporaries.

[Images of Gilbert Newton Lewis and John Goodenough]
### Chemistry selection – Why Lithium-ion?

<table>
<thead>
<tr>
<th></th>
<th>Lead Acid</th>
<th>Ni-MH</th>
<th>Li-Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nominal Voltage</strong></td>
<td>2V</td>
<td>1.2V</td>
<td>3.7V</td>
</tr>
<tr>
<td><strong>Cycle Life</strong></td>
<td>500</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>(80% capacity)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Self Discharge</strong></td>
<td>5%</td>
<td>30%</td>
<td>5%</td>
</tr>
<tr>
<td>(% per month at 25°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>180 W/kg</td>
<td>1,000 W/kg</td>
<td>2,000 W/kg</td>
</tr>
</tbody>
</table>

### Gravimetric Energy Density (Wh/kg)

<table>
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**SMALLER**

**LIGHTER**
## Li-ion – Advantages / Disadvantages

<table>
<thead>
<tr>
<th>ADVANTAGES:</th>
<th>DISADVANTAGES:</th>
</tr>
</thead>
<tbody>
<tr>
<td>High energy density</td>
<td>Protection Li-ion are sensitive to temperature and the chemistry is complex therefore circuitry is required to protect against over-charge, over-discharge, and over temperature.</td>
</tr>
<tr>
<td>compared to other chemistries opportunity to increase capacity</td>
<td></td>
</tr>
<tr>
<td>Small package size and weight, ideal for portable consumer products. Prismatic package typically thinner than 19mm; pouch typically thinner than 5mm.</td>
<td>Premature ageing Li-ion are susceptible to capacity deterioration over time; however storage of the battery in a cool environment can reduce the effects.</td>
</tr>
<tr>
<td>Memory effect - unlike Ni-Cd, Li-Ion batteries do not suffer from “memory effect”. Memory effect occurs where over time a battery has been consistently partly used and then fully recharged which results in the appearance of rapid discharge.</td>
<td>Chemistry severe temperature or mechanical impact can result in venting and possible thermal runaway. Requires more extensive testing than other chemistries.</td>
</tr>
<tr>
<td>Low discharge rate - compared with other rechargeable batteries Li-ion have a low self-discharge rate which means they can be left unused for longer.</td>
<td>Production costs compared to other types of rechargeable battery production costs can be high.</td>
</tr>
</tbody>
</table>
Typical Applications for Li-ion

- **Consumer**
  - Mobile Phones
  - Power Tools
  - Laptops

- **Medical**
  - Cardiac Defibrillators
  - Portable Ventilators
  - Implantable Cochlear

- **Industrial**
  - Portable Meters
  - Oil & Gas Pipeline Robots
  - Seismic Survey Sensors

- **Military**
  - Thermal Imaging Equipment
  - Radio
  - Bomb Disposal Robot

- **Aerospace**
  - Satellite Power Sources
  - Aircraft Auxiliary Power Units

- **Automotive**
  - Cars, Bikes, Trucks, Buses
Basic construction

The lithium-ion cell is available in three main types of package “cylindrical”, “prismatic” and in the case of lithium polymer “pouch” designs; however the basic construction of each type is virtually identical.
Basic Construction

**Electrodes:**
Modern lithium-ion batteries do not actually contain lithium metal due to its inherent instability during cycling.

Today the electrodes are made from materials such as lithium cobaltate (for the cathode) and graphite (for the anode).

The selection of electrode material is important for capacity, voltage, energy and power capability of the cell.

**Separator:**

The main function of the separator is to insulate the positive and negative electrodes, retain the electrolyte and allow the flow of ions (semi porous).

The separator material is very thin but needs to be resistant to penetration by burr on the electrode plates and have good insulation, mechanical strength plus chemical & thermal stability.

**Electrolyte:**

The electrolyte is an organic solvent (lithium salt) rather than a water-based electrolyte used in other chemistries such as alkaline cells and has the function of carrying lithium-ions and so producing current flow. It is highly conductive with a high temperature range. Unlike other chemistries, as the electrolyte a solvent it has potential to be highly flammable when in contact with air and release more heat.

Difference between a Lithium ion and Lithium ion polymer cell is the electrolyte which in a polymer cell is a gel with minimal liquid so reducing the flammability and enhancing flexibility.
Public confidence shaken?

Negative Press Coverage relating to Li-ion Batteries

► Fire

► Explosions

► Product Recalls

► Personal Injuries

► Product Liability

FAA reported 118 air incidents from May 1991 – 2011 relating to batteries

Exploding cell phones prompt battery recalls

By Elizabeth Wolfe
Associated Press

WASHINGTON — Curtis Sather said it was like a bomb going off. His 13-year-old son, Michael, stood stunned, his ears ringing, his hair burned, blood and soot covering his face.

In a split second last August, fragments from Michael’s exploding cell phone hit him between the eyes and lodged in the ceiling of the family’s home in Oceanside, Calif.

Over the past two years, federal safety officials have received 85 reports of cell phones exploding or catching fire, usually because of incompatible, faulty or counterfeit batteries or chargers. Burns to the face, neck, leg and hip are among the dozen of injury reports the agency has received.

The Consumer Product Safety Commission is providing tips for cell phone users to avoid such accidents and has stepped up oversight of the wireless industry. There have been three voluntary battery recalls, and the CPSC is working with companies to create better battery standards.

"CPSC is receiving more and more reports of incidents involving cell phones, and we’re very concerned of the potential for more serious injuries or more fires," said agency spokesman Scott Wolfson.
So what are the reasons behind these incidents?

The increase in capacity is certainly part of the reason, placing greater pressure on design tolerances.

Many of the high profile incidents involving lap-top computers in 2006 & 2007 have been linked to potentially inadequate procedures relating to the avoidance of contaminates in production. Metal particles penetrated the separator and caused a short circuit between the cathode and the anode resulting in thermal runaway.

Another area of concern is non-genuine batteries and chargers; consumers being tempted by lower prices without realising the potential safety implications and the use of chargers and batteries not intended for the application.

Inadequate charging and protection circuitry in the end product and battery.
### Battery Testing – Selection of Battery Standard

<table>
<thead>
<tr>
<th>Chemistry</th>
<th>Lead Acid</th>
<th>Lithium ion</th>
<th>Alkaline</th>
<th>Nickel-Metal Hydride</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>Primary</td>
<td>(non chargeable)</td>
<td>Secondary</td>
<td>(rechargeable)</td>
</tr>
<tr>
<td><strong>End Application</strong></td>
<td>Consumer</td>
<td>Vehicle</td>
<td>Portable</td>
<td>Stationary</td>
</tr>
<tr>
<td><strong>Target Market</strong></td>
<td>Europe (EN)</td>
<td>America (ANSI, UL)</td>
<td>Global (IEC, ISO)</td>
<td>Local Market requirements (PSE, GOST, TISI)</td>
</tr>
<tr>
<td></td>
<td>International Certification (IECEE CB Scheme)</td>
<td>Trade Association requirements (CTIA, ICEL, SAE, BATSO)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Example mobile phone battery:**

- [Cell](#) UN Manual of test IEC / EN 62133 UL 1642
- [Pack](#) UN Manual of test IEC / EN 62133 UL 2054
- [Mobile Phone](#) IEC / EN 60950-1 UL 60950-1

**Objective:** Safety, Performance

Consideration to complete system interaction testing is important.
Battery Testing – Failure Modes

- **Elevated Temperature**
  - Internal Short Circuit
  - Overcharge
  - Overdischarge
  - Overload
  - External Heating
- **External Short Circuit**
- **Thermal Runaway**
  - External Heating
  - Rupture
- **Venting**
  - Fire
  - Explosion

**PARTICLE**
**DENDRITES**
**IMPACT**
Different standards call for various tests depending on the end application of the product the battery is powering.

<table>
<thead>
<tr>
<th>ELECTRICAL TESTING</th>
<th>MECHANICAL TESTING</th>
<th>ABUSE TESTING &amp; OTHERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power availability</td>
<td>Crush</td>
<td>Immersion</td>
</tr>
<tr>
<td>Capacity / Energy density measurement</td>
<td>Crash</td>
<td>Short-circuit (external, partial)</td>
</tr>
<tr>
<td>Self-discharge test</td>
<td>Vibration / Shock / Drop</td>
<td>Overcharge</td>
</tr>
<tr>
<td>Rapid charge / discharge</td>
<td>Altitude simulation</td>
<td>Fire test</td>
</tr>
<tr>
<td>Dynamic discharge performance</td>
<td>Projectile</td>
<td>Forced discharge</td>
</tr>
<tr>
<td>Parameter measurement</td>
<td>Roll over</td>
<td></td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>Nail / Penetration test</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HALT / HASS</td>
<td></td>
</tr>
<tr>
<td>ENVIRONMENTAL TESTING</td>
<td>LIFECYCLE TESTING</td>
<td>ELECTROMAGNETIC (EMC) CAPABILITIES</td>
</tr>
<tr>
<td>Thermal abuse</td>
<td>Dynamic endurance test</td>
<td>Radiated emissions</td>
</tr>
<tr>
<td>Elevated temperature storage</td>
<td>Cycle life test</td>
<td>Radiated immunity</td>
</tr>
<tr>
<td>Extreme cold / heat</td>
<td>Environmental cycle testing</td>
<td>Conducted emissions</td>
</tr>
<tr>
<td>Temperature cycling / shock</td>
<td>Vibration cycle testing</td>
<td>Conducted immunity</td>
</tr>
<tr>
<td>Corrosion</td>
<td></td>
<td>Electrostatic discharge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Battery Testing – Example Standard

TRANSPORT OF DANGEROUS GOODS
UN Manual of Tests and Criteria - Section 38.3 Lithium Batteries ST/SG/AC.10/11/

• Essential to aid the transportation of Lithium metal or Lithium ion cells and batteries by land, sea & air.

• Required by such organisations as
  - IATA (International Air Transport Association)
  - IMO (International Maritime Organisation)
  - ADR (Road) & RID (Rail)

• Demonstrates your cell/pack is safe for transportation.

• Applies to both Primary & Secondary cells and batteries.

• Recommended to source cells already tested to UN Manual of Test to minimise testing of your pack.

• Applicable to a variety of applications from coin cells to EV modules.
# UN Dangerous Goods Classifications

<table>
<thead>
<tr>
<th>UN Class</th>
<th>Description</th>
<th>Typical Warning Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Explosive</td>
<td><img src="image" alt="Explosives Label" /></td>
</tr>
<tr>
<td></td>
<td>Dynamite, Fireworks</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Gases</td>
<td><img src="image" alt="Flammable Gas Label" /></td>
</tr>
<tr>
<td></td>
<td>Aerosols, Hydrogen, Nitrogen, Fluorine</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Flammable Liquids</td>
<td><img src="image" alt="Flammable Liquid Label" /></td>
</tr>
<tr>
<td></td>
<td>Kerosene, Diesel, Petrol</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Flammable Solids</td>
<td><img src="image" alt="Flammable Solid Label" /></td>
</tr>
<tr>
<td></td>
<td>Matches, Sulphur, Lithium</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Oxidising Substances &amp; Organic Peroxides</td>
<td><img src="image" alt="Oxidising Substance Label" /></td>
</tr>
<tr>
<td></td>
<td>Ammonium Nitrate, Benzoyl Peroxides</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Toxic &amp; Infectious Substances</td>
<td><img src="image" alt="Poison Label" /></td>
</tr>
<tr>
<td></td>
<td>Pesticides, Lead, Arsenic</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Radioactive Material</td>
<td><img src="image" alt="Radioactive Label" /></td>
</tr>
<tr>
<td></td>
<td>Uranium, Plutonium</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Corrosive Substances</td>
<td><img src="image" alt="Corrosive Label" /></td>
</tr>
<tr>
<td></td>
<td>Sulphuric acid, Sodium Hydroxide</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Miscellaneous Dangerous Goods</td>
<td><img src="image" alt="Miscellaneous Label" /></td>
</tr>
<tr>
<td></td>
<td>Dry Ice, Lithium Metal and Ion Batteries,</td>
<td></td>
</tr>
</tbody>
</table>
### UN Requirements for Lithium Cells & Batteries

<table>
<thead>
<tr>
<th>Description</th>
<th>UN Number</th>
<th>Packing Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium ion Batteries</td>
<td>UN 3480</td>
<td>965</td>
</tr>
<tr>
<td>Lithium ion Batteries contained in equipment</td>
<td>UN 3481</td>
<td>967</td>
</tr>
<tr>
<td>Lithium ion Batteries packed in equipment</td>
<td>UN 3481</td>
<td>966</td>
</tr>
<tr>
<td>Lithium Metal Batteries</td>
<td>UN 3090</td>
<td>968</td>
</tr>
<tr>
<td>Lithium Metal Batteries contained in equipment</td>
<td>UN 3091</td>
<td>970</td>
</tr>
<tr>
<td>Lithium Metal Batteries packed in equipment</td>
<td>UN 3091</td>
<td>969</td>
</tr>
</tbody>
</table>

**General Requirements:**

Must meet the requirements of UN Manual of Test.
Waste batteries being transported by air for recycling or disposal not permitted unless approval is sort from the country of origin and the country of the airline operator.
Cells / Batteries that are defective (safety returns) are forbidden for air transport.
Must be protected from short circuits; consideration shall be given to conductive packaging material.
When packed within equipment accidental activation is prevented.

Packing notes dived into 2 categories “Regulated Class 9” & “Excepted”

“Excepted “are classified as cells (≤ 20Wh / ≤ 1g) and Batteries (≤ 100Wh / ≤ 2g) less stringent packaging requirements.
General Labelling requirements
<table>
<thead>
<tr>
<th>Test</th>
<th>Cell</th>
<th>Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 Altitude Simulation</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>T2 Thermal</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>T3 Vibration</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>T4 Shock</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>T5 External Short Circuit</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>T6 Impact</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>T7 Overcharge</td>
<td>✗</td>
<td>✔</td>
</tr>
<tr>
<td>T8 Forced Discharge</td>
<td>✔</td>
<td>✗</td>
</tr>
</tbody>
</table>

T7 test only applies to secondary batteries.
Mainly relates to larger cells & batteries:

Small vs large cells:
- >150Wh (Lithium ion)
- lithium anode content >12g (Lithium metal)

Small vs large battery:
- >12kg gross weight

Small vs large battery assembly:
- >6200Wh (Lithium ion)
- lithium anode content >500g (Lithium metal)

What is the significance?

• Less samples required for rechargeable large batteries.

• Limited testing for small battery assemblies & only 1 sample required T3, T4, T5, T7 (if cell /batteries passed all tests successfully).

• No testing required for large battery assembly (example EV Battery Pack) if batteries (example EV Module) passed all tests successfully and batteries are monitored by a system preventing short circuits and over discharge between batteries as well as overheating and overcharging of the battery assembly.
### UN Manual of Test – Sample Requirements

<table>
<thead>
<tr>
<th>CELLS</th>
<th>1st Cycle Charged</th>
<th>1st Cycle Discharged</th>
<th>50% Rated Capacity</th>
<th>Charged after 50 Cycles</th>
<th>Discharged</th>
<th>Charged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>25 *</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>extra 5 samples required for T6 if the cell is prismatic</td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BATTERY (Large)</th>
<th>1st Cycle Charged</th>
<th>1st Cycle Discharged</th>
<th>50% Rated Capacity</th>
<th>Charged after 50 Cycles</th>
<th>Discharged</th>
<th>Charged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4 (4)</td>
<td>4 (4)</td>
</tr>
<tr>
<td>Secondary</td>
<td>8 (4)</td>
<td>-</td>
<td>-</td>
<td>8 (4)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* 25 Cycles only
**Purpose:**
To verify that the cell / pack remains safe during low pressure transportation; e.g. plane cargo hold

**Test Method:**
- Chamber gradually reduced to 11.6kPa (simulates 15,240m altitude)
- Test Duration - 6 hours
- Ambient Temperature 20°C

**Pass Criteria:**
- No fire, disassembly, leakage, venting, mass loss
- No rupture
- $V_{oc}$ within 90% of pre test voltage.
**Purpose:**

To test the cell/battery seal integrity and internal connections when exposed to repeated temperature extremes.

**Test Method:**

Temperature extremes maintained for 6 hours (12 hours for large cells/batteries):

\[ +75 \degree C / -40 \degree C \] 10 cycles

Temperature transition - \( \leq 30 \) minutes

“Rest” temperature is 20\( \degree \)C for 24 hours

**Pass Criteria:**

No fire, disassembly, leakage, venting, mass loss, rupture

\( V_{oc} \) within 90% of pre test voltage.
Purpose:
Simulates vibration that can occur during transportation.

Test Method:
- Frequency ranges 7-200-7 Hz in 15 minutes
- Cycle repeated 12 times for 3 hours
- 3 mutually perpendicular planes
- 1 direction shall be perpendicular to terminal face
- Peak Acceleration \( g_n \):
  - 7 – 18 Hz: \( 1g_n \)
  - 18 – 200 Hz: \( 8g_n \)

Pass Criteria:
No fire, disassembly, leakage, venting, mass loss, rupture
\( V_{oc} \) within 90% of pre test voltage.
Purpose:
Simulates impacts that could occur during transportation.

Test Method:
- Half sine shock at:
  - 150g_n for 6 ms (small cells & batteries)
  - 50gn for 11 ms (large cells & batteries)
- 3 shocks in each direction
- 3 mutually perpendicular mounting positions x, y, z axis
- Total of 18 shocks

Pass Criteria:
No fire, disassembly, leakage, venting, mass loss, rupture
$V_{oc}$ within 90% of pre-test voltage.
Purpose:
To replicate a short circuit of the positive and negative terminals.

Typical Test Method:
• External resistance less than 100mΩ
• Tests performed at 55°C
• Test Duration 1 hour after the enclosure returns to 55°C
• Observation period after test 6 hours

Pass Criteria:
No fire, disassembly, rupture
No excessive temperatures (<170°C)
T6 Impact Test

**Purpose:**
To simulate impacts that could be reasonably expected during transportation

**Test Method:**
- Cell positioned on a flat surface; 1 impact per sample
- 15.8 mm diameter bar placed across the cell
- 9.1kg weight dropped from 61cm
- Observation period after test 6 hours

**Pass Criteria:**
- No fire, disassembly
- No excessive temperatures (<170°C)
T7 Overcharge

Purpose:
To test the ability of a fully charged pack to withstand an overcharge condition

Test Method:
• 2x manufacturer's recommended continuous charge current
• 2x manufacturer's recommended continuous charge voltage or 22V (whichever is lower)
• If manufacturers recommended continuous charge voltage is ≥ 18V; test voltage shall be 1.5x
• Test Duration: 24 hours
• Visual inspection after 7 days

Pass Criteria:
No disassembly or fire
T8 Forced Discharge

Purpose:
To evaluate the ability of a discharged cell to withstand an forced discharged condition.

Test Method:
• Cell connected in series to 12 V dc supply with a load resistor
• Load resistor shall be appropriately rated for the test (12V, Max Charge current)
• Duration of test is calculated:

  Rated Capacity(A/h) / Max Discharge Current (A)

• Visual inspection after 7 days

Pass Criteria:
No disassembly or fire
1. Vent Plate / Vent Tear Away Tab

Excessive build up of pressure within battery cells is caused primarily from excessive abnormal heat generation or over-charging. The vent allows the safe release of gas.

1 Safety vent
2 Seal
3 Positive plate
4 Separator
5 Negative plate
6 Nickel-plated steel case
2. Positive Temperature Coefficient (PTC)

PTC’s act as both a current fuse and a thermal fuse so that when excessive current is drawn the resistance of the PTC increases resulting in increased heat generation. The resistance of the PTC is selected so that it trips at the pre-determined current.

Product Type Features:
UL Recognized = File No. E74889

Electrical Characteristics:
IH (Room Temperature) (Amps.) = 2.1
IT (Room Temperature) (Amps.) = 4.70
Vmax Operating (V) = 16
Rmin (Ω) = 0.018
Rmax (Ω) = 0.030
R1 Max [Post Trip] (Ω) = 0.06
UL Rated Current (Amps.) = 100
Tripped Power Dissipation (Typical) (W) = 1.50

Termination Related Features:
Construction = Weldable Strap
3. Separator

When the separator reaches its defined temperature (typically 130°C) the pores are blocked by the melting of the material preventing electrical current to flow between the electrodes. The separator is also sometimes known as a shut-down separator.

Polyolefin flat-film membrane used as lithium ion battery separators. Flat-film membranes look like plastic films, but are actually filled with microscopic pores. Thicknesses range from 25µm to several hundred µm, with uniform pore sizes ranging from 0.05 to 0.5µm.
4. Thermal Fuse

Some prismatic batteries have an additional feature, a thermal fuse which limits the current under fault conditions.
Safety Features

A protection circuit (PCM) is usually fitted within the battery pack consisting of a custom designed controller IC that monitors the cell and prevents overcharge (>4.3V), over discharge (< 2.5 V), and over current. This in combination with two FET devices control the charge and discharging. Also present is a temperature sensing device (thermistor) designed to invoke protective action via the control IC in the event of an over-temperature scenario.
Safety Design Considerations

- Ambient Temperature – Check that charging/discharging is prohibited in excessive temperatures (low/high). Consider radiated heat from components in the proximity of the battery cell/pack.

- Overcharge protection - Are appropriate voltage and current limits set and maintained under normal and single fault conditions?

- Over discharge protection - Are appropriate voltage and current limits set and maintained under normal and single fault conditions?

- Overcurrent protection – Suitable protection device fitted such as PTC/Fuse etc.

- Overvoltage protection – Is the power management circuitry protected from other circuits of higher voltages including under faults conditions. Consider complete end system.

- Algorithm design – Are the correct voltage/current applied at the correct stages of the charge cycle, for the right duration and under the correct conditions?
Safety Design Considerations

- Short circuit avoidance – ensure the design minimises accidental short circuit in terms of detached wires and separation distances between pads/tracks for example.

- Leakage Protection – Mitigate hazards from contamination of protection circuits should the cell leak. Electrolyte has corrosive and conductive properties.

- Cell Vent – Ensure that in end application the vent is not blocked or restricted

- User Instructions - Appropriate instructions to reduce hazards to user and damage to product which could result in a safety hazard. For example ambient conditions of use, use of correct power adapter and disposal of product at end of life.

- Multi-Cell Packs - require more complex Battery Management Systems to control higher voltages and current, individual cell monitoring, SMBus, CAN protocols, fuel gauging.

- The robustness of the design should be verified by testing under normal and fault conditions.
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