

## Safety Standards for Lithium-Ion Cells

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Advances in portable energy sources, such as rechargeable cells (or batteries), are a major technological driver for the popularity of many electronic and electrical devices from consumer products to medical equipment to automotive systems to space applications. For a rechargeable cell to be commercially viable, it must satisfy numerous performance requirements such as long cycle life, low cost, high power density and high energy density - just to name a few - without posing a hazard. For now, lithium-ion cells appear to be the leading candidate for rechargeable portable energy sources; its worldwide market is projected to reach nearly \$9 billion (USD) in annual sales by 2014<sup>1</sup>. Simply put, there are a lot of lithium-ion cells out on the market with more to come.

Though the lithium-ion cell is designed with integrated passive safeguards (and active safeguards in the case of pack designs), the sheer number of lithium-ion cells, the complexity of the cell, and the numerous usage conditions present challenges not only for design of safe cells, but also the design of tests for battery safety standards.



**Figure 1. CT Scan of a cylindrical lithium ion cell.**

For a product, such as a lithium-ion cell, with more than a billion sold in the market over the last decade, the number of failures, though relatively small, should not be discounted; this is even the case when Six-Sigma has been used in the development of these batteries. The well-publicized incidents with laptops in 2006, where it was reported that the battery burst into flames, have been linked to manufacturing defects in the lithium-ion cell<sup>2</sup>. Just a few cases resulted in a recall of over 4 million units<sup>3</sup>. Another challenge: the large number of applications and users increases the probability that a cell may experience an unanticipated abuse condition. Also, failures need not occur only during usage as demonstrated by fires on some cargo planes carrying bulk shipments of lithium-ion cells. These

incidents have UN and FAA regulators concerned about safe handling procedures. As if these challenges were not enough for developers of battery safety standards, lithium-ion cell designers and researchers are intensely involved in creating new designs to improve performance and safety. As a simple measure of this activity, a search on Google Scholar using the key words 'lithium ion cell safety' delivered over 50,000 article citations<sup>4</sup>.

As product recalls undermine public confidence, it is imperative to promote the safe commercialization of lithium-ion cells by ensuring that consensus-based battery safety standards such as UL 1642 and IEC 62133 effectively capture the fast changing pace of lithium-ion cell safety and design knowledge. The ability to access and translate results of battery safety research and field failure information into a safety standard can only be properly addressed through the open cooperation of governmental research organizations, cell manufacturers, safety officials, and standards organizations.

### **Internal Short Circuits and Safety Standards**

A review of the publicly available lithium-ion battery safety research shows a strong focus on understanding and mitigating cell failure modes, specifically those due to internal short circuits. Though only brief accounts of field failures are available, in some cases, the presence of manufacturing defects has been noted to lead to internal short circuits within the cell. The highly localized joule heating then can act as an initiator for exothermic self-sustaining chemical reactions of the active materials (thermal runaway) within the cell possibly generating high temperatures and pressures (depending upon many factors such as thermal stability of active materials, heat dissipation rate, etc.), on a scale faster than the integrated safety mechanisms can sometimes react. This high pressure and temperature condition could compromise the integrity of the cell casing<sup>5</sup>, violently releasing volatiles gases which may further ignite.

Applying a hazard analysis methodology<sup>6</sup> shows that there can be many root causes for an internal short circuit in a cell. This certainly precludes the possibility of a single safety test that can assess the robustness of a lithium-ion cell under conditions of an internal short circuit. This is also partly due to the various configurations of lithium-ion cells (cylindrical, prismatic, and pouch) and multi-cell (module/pack) packaging. Battery safety standards and testing protocols incorporate a number of product safety tests designed to assess a battery's ability to withstand certain types of abuse (Table 1). Yet, a survey of most lithium-ion battery safety standards and testing protocols (Table 1) shows that there is no generally accepted internal short circuit specific test<sup>7</sup>.

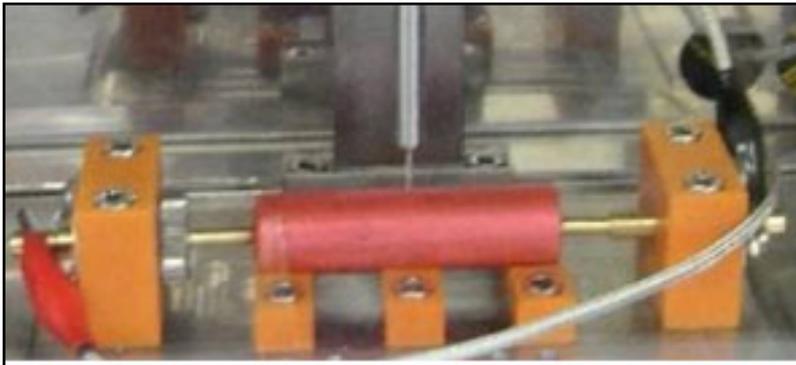
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Test Criteria/Standard	UL					IEC		NEMA	SAE	UN	IEEE		JIS	BATSO
	UL 1642	UL 2054	UL Subject 2271	UL Subject 2580	UL 2575	IEC 62133	IEC 62281	C18.2M, P12	J2464	PLIII,S 38.3	IEEE 1625	IEEE 1725	JIS C8714	BATSO 01
External short circuit	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Abnormal charge	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Forced discharge	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Crush	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Impact	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Shock	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Vibration	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Heating	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Temperature cycling	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Low pressure (altitude)	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Projectile	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Drop	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Continuous low rate charging	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Molded casing heating test	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Open circuit voltage	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Insulation resistance	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Reverse charge	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Penetration	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Internal short circuit test	*	*	*	*	*	*	*	*	*	*	*	*	*	*

**Table 1. Summary of abuse tests within International safety standards and testing protocols for lithium-ion batteries.**

Currently, there are only two new internal short circuits (ISC) tests, which are either under consideration or part of some consensus-based standards. One is the Forced Internal Short Circuit (FISC) test and the other, developed by Underwriters Laboratories Inc. (UL) is the Indentation Induced Internal Short Circuit test. The FISC requires the disassembly of the cell with testing being conducted on the cell (without a casing) making it useful mainly for research studies. Generally, the disassembly of a cell is not considered a best practice for tests in safety standards<sup>8</sup>. The Indentation Induced ISC test forces an internal short circuit condition by subjecting the lithium-ion cell to a localized indentation<sup>9</sup>. The indentation eventually leads to an internal short (as measured by a sudden drop in the open circuit voltage), which may initiate thermal runaway and an explosive failure of the cell depending upon many factors (such as thermal stability of active materials, separator integrity, etc.). Though most testing has been carried out on cylindrical cells, prismatic and pouch cells have been tested showing promise for this indentation type methodology as a basis for an ISC test.



**Figure 2. Picture of Indentation Induced ISC test.**

Now the typical risk measure consists of severity of failure multiplied by probability of failure. In forcing a failure, the Indentation Type ISC test is basically measuring the severity of cell failure. This approach is one that has been adopted by NASA in screening rechargeable batteries for space applications. Cells that do not perform well under this type of test would then be subjected to more stringent secondary testing schedule that might help establish the probability of ISC cell failure. UL is presently working closely with NASA Johnson Space Center to improve the current indentation type ISC test. In another collaboration, UL and Argonne National Laboratory (ANL) are considering how to translate some cutting edge battery safety research into alternative ISC test methodologies for safety standards such as UL 1642.

### Challenges For Battery Safety Standards

Research into the safety performance of lithium-ion cells is ongoing and the ability to take research level understanding and testing and develop a test method suitable for safety standards is a formidable task. In addition, lithium-ion cells are not only being used in small numbers to power a hand-held device, but many thousands of these cells are packaged with monitoring systems to power electric vehicles and possibly space vehicles. Considering the effort in understanding and mitigating the failure of a single cell, these challenges are likely to be increased many-fold for battery modules and packs. At UL, Standard Technical Panels for each UL standard bring together volunteer experts and key stakeholders for each product family. As recalls for lithium-ion powered products still occasionally make headlines, the need for an open and cooperative dialogue to share information on the failure modes of lithium-ion cells and help develop ISC tests for consensus-based safety standards is ever important.

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[1] <http://www.bccresearch.com>