



FY 2020 Status Report and Action Plan for the High-Energy Density Batteries Project

March 2020

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1. Introduction

This report provides an update on U.S. Consumer Product Safety Commission (CPSC) technical staff's activities supporting the High-Energy Density Batteries Project since the last status report in February 2018. The report includes an action plan outlining the direction of staff's future efforts.¹ This report was specified in the Fiscal Year (FY) 2020 Operating Plan as Milestone 04. The overall goal of the project, initiated in FY 2017, is to improve the safety of high-energy density batteries, primarily those using lithium-ion-based electrodes and electrolytes, and consumer products using these batteries.

2. Improving battery and battery-powered product standards

Staff continues to work on voluntary safety standards for cells, batteries, and battery-powered products.

Staff has participated in the development and revisions of IEEE 1725-2011, *Rechargeable Batteries for Cellular Telephones*, and IEEE 1625-2008, *Rechargeable Batteries for Multi-Cell Mobile Computing Devices*, to help mitigate hazards with cellular telephones and laptops (portable computers). CTIA,² which represents the U.S. wireless communications industry and companies throughout the mobile telephone system, uses IEEE 1625 and IEEE 1725 as the foundations for certification of battery-powered cellular telephones and mobile computing products.

In late 2017, after the [Samsung Galaxy Note 7 Recall](#), staff initiated discussions with CTIA to review and revise IEEE 1725-2011 and IEEE 1625-2008. In 2018, CTIA informed staff that they were going to initiate the process of revising IEEE 1725, and that, as they had done for the 2008 edition, IEEE was going to require IEEE-SA Corporate Membership dues for interested parties to participate in the process (CPSC staff did not participate in the development of the 2011 edition because our incident data at the time did not support any major issues ongoing with these types of products). The dues (\$1,250 for a basic [non-voting] membership or \$3,500 for an advanced [voting] membership) cover IEEE's administrative costs of updating the standard. Although staff and other stakeholders (including a battery manufacturer with a large share in the cell phone market) expressed concerns to CTIA about the lack of openness created by requiring dues for participation in the process, IEEE maintained commitment to their plan to collect IEEE-SA Corporate Membership dues. The CTIA chair leading this revision also offered to designate CPSC staff technical experts, which would allow staff participation without paying dues. However, staff declined, because this fee structure would still limit attendance at meetings, and staff must abide by CPSC's open meetings policy. Staff discontinued active participation in this process, but staff continues to monitor the activity of the IEEE committee and also works to improve the safety of cell phone electrical systems through participation in safety standards with

¹ https://www.cpsc.gov/s3fs-public/High_Energy_Density_Batteries_Status_Report_2_12_18.pdf?UksG80UJqGY0q4pfVBkbCuUQ5sNHqtwo

² <https://www.ctia.org/about-ctia/our-mission>

open processes, including UL 1642 - *Lithium Batteries*, UL 62133 *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 - Part 2: Lithium Systems*, UL 62368-1 *Audio/Video, Information and Communication Technology Equipment - Part 1: Safety Requirements*, UL 2056 *Outline of Investigation for Safety of Power Banks*, and UL 2849 *Standard for Electrical Systems for eBikes*.

3. Outreach

In FY 2019, staff continued to promote lithium battery safety best practices to manufacturers, importers, retailers, and members of the academic community. In March 2019, staff presented on the safety of battery-powered consumer products and hosted a roundtable discussion at the International Battery Seminar & Exhibit, which is one of the largest battery safety conferences in North America. The staff presentation is included in Appendix A.

In September 2019, CPSC staff presented *Selling Safe Electrical Products in the U.S.* to retailer buyers in China and South Korea. This presentation included case studies and highlighted recalls that included consumer products with high-energy batteries, such as hoverboards. The presentation, Appendix B, emphasized the importance of choosing a product that has been certified to ensure it meets applicable standards and a certification mark gives consumers an easy way to identify conformity.

4. Collaborating with external partners and stakeholders

Staff collaborated with many external partners and stakeholders to leverage additional resources to reduce the likelihood of battery-related fires:

- Battery Safety Council (BSC) – In 2015, the National Transportation Safety Board (NTSB) and UL formed the BSC after investigating lithium battery failures on aircraft. The intent of the BSC is to provide an open forum for the sharing and resolution of battery-related safety issues faced by the battery industry and users. This includes aspects related to consumer use, the electrical grid (including microgrids and nanogrids, which are local or single-building energy grids with control capability that can disconnect from the traditional grid and operate autonomously), transportation, aviation, defense, space, and innovative/integrative applications. Staff attended a BSC meeting at the American Airlines headquarters in January 2019, and another in Washington, DC, in November 2019.
- Lithium Battery Inter-Agency Coordination Group (LBIACG) - The LBIACG was formed in fall 2016, in the aftermath of the Samsung Note 7 recall, to improve cross-agency communications on battery safety issues. The LBIACG is co-chaired by members of the founding agencies -- CPSC and the Pipeline and Hazardous Materials Safety Administration (PHMSA). The LBIACG is open to all federal government agencies and has progressively added agencies that have the following interests:

- Administrative, regulatory, or law enforcement purview over lithium batteries;
- Commitment to partnerships that consider a broad public policy perspective and openness to support solutions that serve the broader safety interest; and
- A willingness to participate in joint safety and/or enforcement efforts.

Staff participated in meetings where staff discussed the agency's High-Energy Density Battery project to mitigate fire risks, and worked to coordinate other agency concerns with lithium battery safety. The LBIACG was suspended temporarily when the Lithium Battery Safety Working Group (LBSWG) was formed (detailed in next bullet below). Staff will participate if LBIACG resumes meeting.

- The Lithium Battery Safety Working Group (LBSWG), established in accordance with Section 333(c) of the FAA (Federal Aviation Administration) Reauthorization Act of 2018 (Pub. L. No. 115-254), initiated planning discussions in February 2019. The LBIACG was placed on hold while the LBSWG worked out the details on how to form applicable requirements in accordance with the (FAA) Reauthorization Act. In July 2019, a charter was put in place, and the Secretary of the Department of Transportation staff officially nominated CPSC staff to participate in the LBSWG, along with participants from the Department of Transportation. The LBSWG is tasked to:

(A) Identify and Assess:

- i) additional ways to decrease the risk of fires and explosions from lithium batteries and cells;
- ii) additional ways to assure uniform transportation requirements for both bulk and individual batteries; and
- iii) new or existing technologies that may reduce the fire and explosion risk of lithium batteries and cells; and

(B) Transmit to the appropriate committees of Congress, a report on the assessments conducted under subparagraph (A).

In March 2019, staff met with Michael Pecht, Ph.D., P.E., Chair, Professor, and Director of the Center for Advanced Life Cycle Engineering (CALCE), at the University of Maryland, College Park. Staff provided some background on general electrical safety strategies and on the high-energy batteries project. Dr. Pecht and several of his graduate students shared their research and experience with lithium battery manufacturing and life cycles. Staff also toured several of the CALCE labs where accelerated life-cycle tests are conducted.

- Tri-National Research Project

In February 2019, staff kicked off a collaborative effort with Profeco and Health Canada to execute a mutually -agreed upon test program to evaluate power banks that are currently on the market. This is the second cooperative project that the three countries executed; the first project on Class 2 power supply testing ran from 2015 to 2017. Power banks in this project are the portable rechargeable battery devices that consumers use to

power/charge their handheld electronic devices like cell phones, tablets, and other devices that charge using a USB port. Although readily available in the market place, there is no consensus safety standard for power banks (UL published their own Outline of Investigation UL 2056 in 2015); so most products at this time have not been certified. The three agencies agreed on a testing program that will preliminary evaluate the various power banks on the market. The three agencies will separately sample and test power banks within the capacity range of 1 amp-hour (Ah) to 10 Ah, using the same test procedures. The group agreed that the scope of testing will exclude units capable of jump-starting combustion engines.

During 2019, the three organizations jointly developed the scope and performance testing requirements for the project. The testing is scheduled to be conducted between June and September 2020.

In September 2019, CPSC staff met with safety agencies in China and Korea to discuss issues relating to the safety of consumer products, including:

- Korean Agency for Technology and Standards (KATS)
- Korean Consumer Agency (KCA)
- State Administration for Market Regulation (SAMR)

Common concerns among the safety agencies were incidents involving high-energy lithium-ion batteries, which opened the door to possible future collaboration in sharing solutions to address these concerns.

5. Research

Staff continued their collaboration with the Naval Surface Warfare Center Carderock Division (NSWCCD) through two major efforts. The first was an exploratory evaluation of various approaches to containing the failure in a multi-cell battery pack to a single cell. This work was done to address fire risk in multi-cell battery back-powered products like hoverboards. The [“Report on Evaluation of Cell-to-Cell Propagation in Lithium-Ion Batteries Containing 18650 Sized Cells,”](#) presents the results of testing that CPSC funded NSWCCD to execute under CPSC Contract No. CPSC-I-17-0002. CPSC staff sponsored this interagency agreement to leverage NSWCCD’s expertise in lithium battery failure testing. The objective was to learn more about the catastrophic failures of multi-cell lithium-ion battery packs, such as those used in hoverboards, from a single cell that enters a thermal runaway condition, and to evaluate several methods to isolate the failure to that one cell. This information will support improvements for the voluntary safety standards for electric scooters and other e-mobility devices to reduce the severity of fire incidents.

In this project, NSWCCD conducted a series of tests forcing a single cell in a multi-cell battery pack into thermal runaway, characterizing the propagation to the remaining cells in the pack and investigating ways to limit the failure to the originating cell, either through spacing cells apart, or using separating materials. NSWCCD conducted tests on commercially available lithium ion cell

battery packs consisting of 10 or 20 individual 18650 cells, as well as custom-built packs that NSWCCD assembled from individual 18650 cells and various thermal insulating materials.

NSWCCD's evaluation of the propagation mitigation techniques showed mixed results that warrant further study. In FY 2020, CPSC staff will fund NSWCCD to evaluate further the materials that showed promise in isolating the failure to one cell that enters a thermal runaway condition. Additionally, NSWCCD staff will explore technologies that can detect characteristics of individual cell internal temperatures as a means of identifying increasing temperatures that could lead to thermal runaway. This early-detection technology shows promise to detect and shutdown battery charging or discharging and warn consumers of an impending thermal failure while a product is in use. However, its viability in a consumer product application is still being examined. In addition, NSWCCD will continue evaluating internal short-circuits of lithium cells by conducting nail-penetration tests to evaluate characteristics of thermal runaway and its propagation when used with and without thermal runaway mitigation technologies.

6. New Battery Testing Capabilities

Over the last several years, CPSC staff has been acquiring specialized test equipment to test cells, batteries, and battery-powered products. A significant piece of equipment acquired was the KDY E-Mobility Light Electric Vehicle Test Stand (LVTS). The LVTS allows dynamic testing of the electrical systems for hoverboards, electric scooters, and electric bicycles, by mechanically loading the vehicle. Five additional pieces of equipment were purchased to expand the testing capabilities for high-energy batteries. To incorporate the equipment into the CPSC lab, an expansion of the Electrical Lab to include a High-Energy Density Storage Devices Testing (HEDSDT) space was included in the scope of the tenant improvement allowance for the GSA-CPSC Occupancy Agreement Lease Renewal for 5RP. The HEDSDT Lab will be a 450 sq. ft. space dedicated to safely and efficiently testing high-energy density storage devices, including battery cells and packs used in consumer products, as well as end product testing. Below is a list of the test equipment that will also be installed and used in this Lab:

- **Chroma Battery Cycling Test System**
The high-precision, integrated battery charge/discharge cycle test system is designed for lithium-ion and other cell chemistries.
- **Russell Environmental Chamber**
The temperature chamber allows battery cells and packs to be exposed to extreme temperature and humidity environmental testing to simulate possible consumer use. The chamber is specially designed to contain and vent any excessive pressures and heat generated by a battery cell or pack that may go into thermal runaway during testing.
- **Free-Fall Tester with Remote Control for Lithium Batteries**
The equipment is an explosion-resistant chamber that allows testing of a battery pack up to 5 kg to IEC62133 requirements. IEC 62133-2:2017 specifies requirements and tests for the safe operation of portable sealed secondary lithium cells and batteries containing non-acid electrolyte, under intended use and

reasonably foreseeable misuse conditions. This equipment supports directional drop testing, as prescribed by IEC62133.

- Gravity Impact Tester with Remote Control for Lithium Battery
The equipment is an explosion-proof chamber that allows impact testing of prismatic, coin, cylindrical, and pouch batteries to the UN 38.3, T6 test standard. UN/DOT 38.3 Transportation Testing for Lithium Batteries.
- Advanced Hydraulic-Driven Crushing Tester with Touch Screen & Remote Controller for Li-Ion Battery
The equipment uses an electric hydraulic pump to crush forcibly the battery cells to UN 38.3.4.6 test standard. UN38.3.4.6: LiPoly Battery Impression Test evaluates prismatic, pouch, coin/button cells, and cylindrical cells by crushing it between two flat surfaces.

In FY 2020, staff is planning to purchase a system to evaluate battery management systems (BMS), the supervisory circuits that protect cells from overcharging, overdischarging, external overloads/short circuits, excessive voltages, and excessive temperatures. BMS test equipment simulates a cell or battery to test the BMS in real time. The tests include evaluation of cell-balancing algorithms, safety interlocks, and response to overtemperature. The system will simulate different battery chemistries, industry-standard drive profiles, charge/discharge cycles, thermal runaway, and various faults, to evaluate the BMS used in consumer products.

7. Action Plan

Building on the accomplishments, to date, staff plans to continue to be active and engaged in a range of relevant voluntary standards, as well as outreach efforts and collaborations, to help mitigate high-energy density battery-related fire incidents. Specific plans include the following:

- Staff will continue to participate actively in developing new or improved voluntary safety standards for consumer products powered by lithium-ion batteries, using data to drive the priorities. Staff anticipates participating in the STPs for UL 2056, UL 2272, and UL 2849. Staff also intends to support mechanical staff in developing ASTM standards related to micromobility devices and light electric vehicles, even though these standards may not directly relate to the electrical system of these products. Electrical staff participation is important for cross-reference to correct standards, requirements, and other technical considerations.
- Based on the results of the NSWV Cell-to-Cell Propagation report, staff is looking to develop proposals for UL 2272 to include a fire-containment test to contain flames during a thermal runaway condition, so that it is less likely to extend beyond the vehicle or battery pack enclosure.
- Staff will update CPSC battery safety information on CPSC's website for consumers and industry.

- Staff will continue informational and educational activities, including presentations of CPSC staff findings, and conducting training at various events:
 - 11th Annual Battery Safety Summit in October 2020. CPSC staff has been invited to give a talk within the “Lithium Battery Transportation Safety” session. CPSC staff participation will help educate stakeholders on possible consequences of not following safety standards for consumer products or best practices for cell manufacturing processes.
 - Association of Home Appliance Manufacturers-UL Partnership Meeting in Q2 FY2020.
 - Staff will present and participate in a lithium-ion battery safety solutions workshop in FY 2020 Q3. The workshop is being hosted by Soteria Battery Innovation Group and Clemson University International Center for Automotive Research.
- Staff will continue power bank testing as part of the Tri-National testing program with Health Canada and Profeco. These activities will support an existing UL STP for power banks utilizing lithium-ion cells. UL is seeking additional diversity of membership before the STP moves forward. When UL is ready to move forward with the STP, CPSC will be prepared with technical findings to support any proposals or revisions to the present Outline of Investigation.
- Staff will continue additional equipment acquisitions and completing construction and outfitting of the High-Energy Density Storage Device Testing lab space. This will also require developing equipment operation procedures and specific test procedures to ensure repeatable and reproducible test results.
- Staff will continue to participate in the FAA LBSWG, the BSC, and the LBIACG, if reconvened.

Appendix A: CPSC Presentation at International Battery Seminar 2019

Safer Battery-Powered Consumer Products



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March 26, 2019

International Battery Seminar

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Outline

- Update on Compliance Recalls and Incident Data
- Review of Emerging Hazards and Technology
- Summary of Voluntary Standards Activities
- Research Testing and Data Findings



Electrical Product Hazard Prevention Strategies

CPSC staff promotes electrical safety through a multipronged approach



- Supporting development of and improvements to voluntary standards/codes
- Disseminating safety information to consumers
- Drafting and enforcing technical regulations and bans
- Identifying existing and emerging hazards and recalling products that present a substantial hazard



Technical Regulatory Process

Regulatory process initiated by vote of the Commission or by a petition from an interested party

Some CPSC statutes specify that voluntary standards should be relied upon. A regulation (mandatory requirement) may be issued if:

the current voluntary standard is not likely to adequately reduce the consumer risk

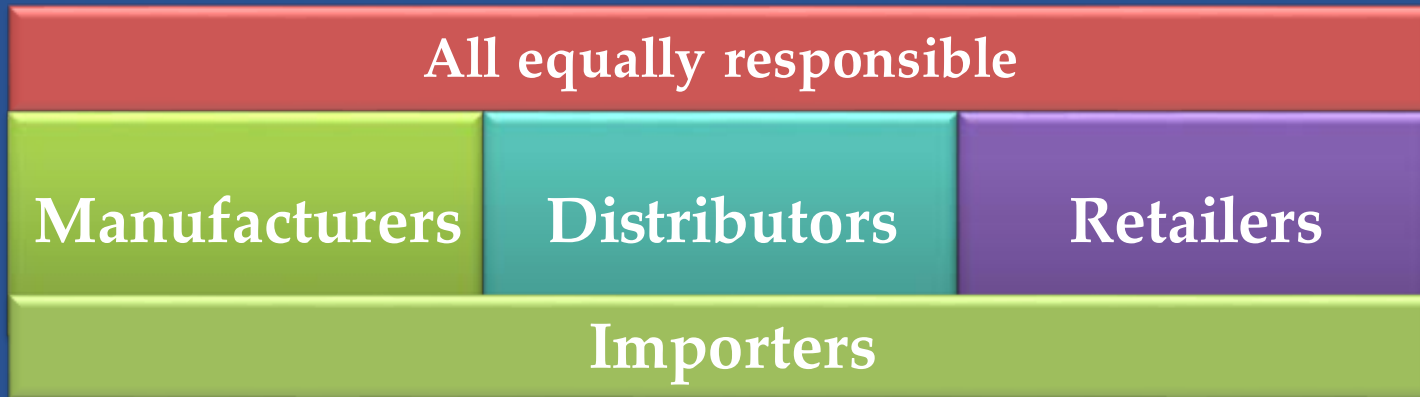
or

there is not likely to be substantial compliance with the voluntary standard.



Responsibility to Comply

- Compliance with applicable regulations and voluntary standards such as the *NEC* are highly effective ways to mitigate hazards from equipment that generates, distributes, or uses electrical energy.



- Importers are directly responsible for the safety of products they bring into the United States.



CPSRMS Incident Data

Consumer Product Safety Risk Management System (2012-2017)

- Anecdotal Incident reports from public sources (NEISS and Compliance data removed)
- Searched Incident reports from 1/1/12 to 7/24/17 using Narrative field search terms:
LI-ION/LITHIUM/POLYMER/
BATTER/CHARG
- Results: Over 25,000 incident reports;
483 primary product codes

Product	Number of Incidents	Number of Products in Use
Computer battery or charger	3000	~250 million (* 2016 data)
Cell phone battery or charger	2000	~396 million (** 2016 data)
Power Banks (Portable USB charger)	400	millions

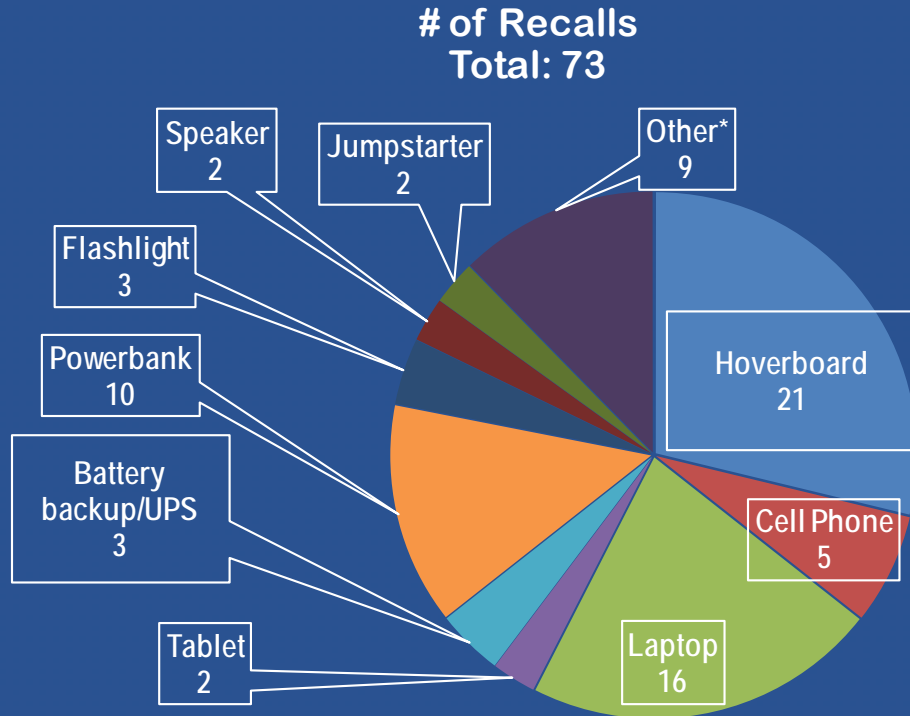
Source: *<http://www.pewinternet.org/fact-sheet/mobile/>

**<https://www.ctia.org/docs/default-source/default-document-library/ctia-wireless-snapshot.pdf>



Recalls of Lithium-Ion Battery Products (2012-2019)

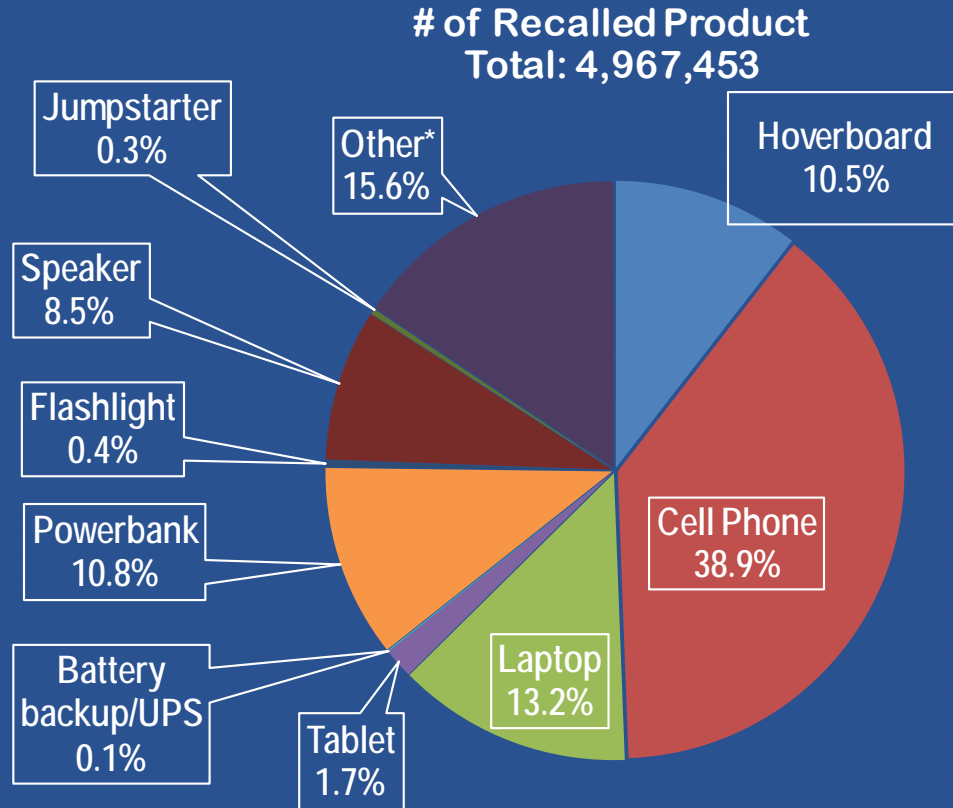
- 73 Recalls (U.S.) of Lithium-ion Battery-Powered Products



*Other products include baby monitor, gloves, hand warmers, RC car battery pack and power tool



Recalls of Lithium-Ion Battery Products (2012-2019)



*Other products include baby monitor, gloves, hand warmers, RC car battery pack and power tool



Recalls of Lithium-Ion Battery Products

- Root Causes
 - Battery Management System (BMS)
 - Cell manufacturing quality control (QC)
 - Lack of system integration (Charger-BMS-Cells)
 - Non-Listed cells/systems
- Standards (voluntary or mandatory)
 - Addressable
 - Non-addressable



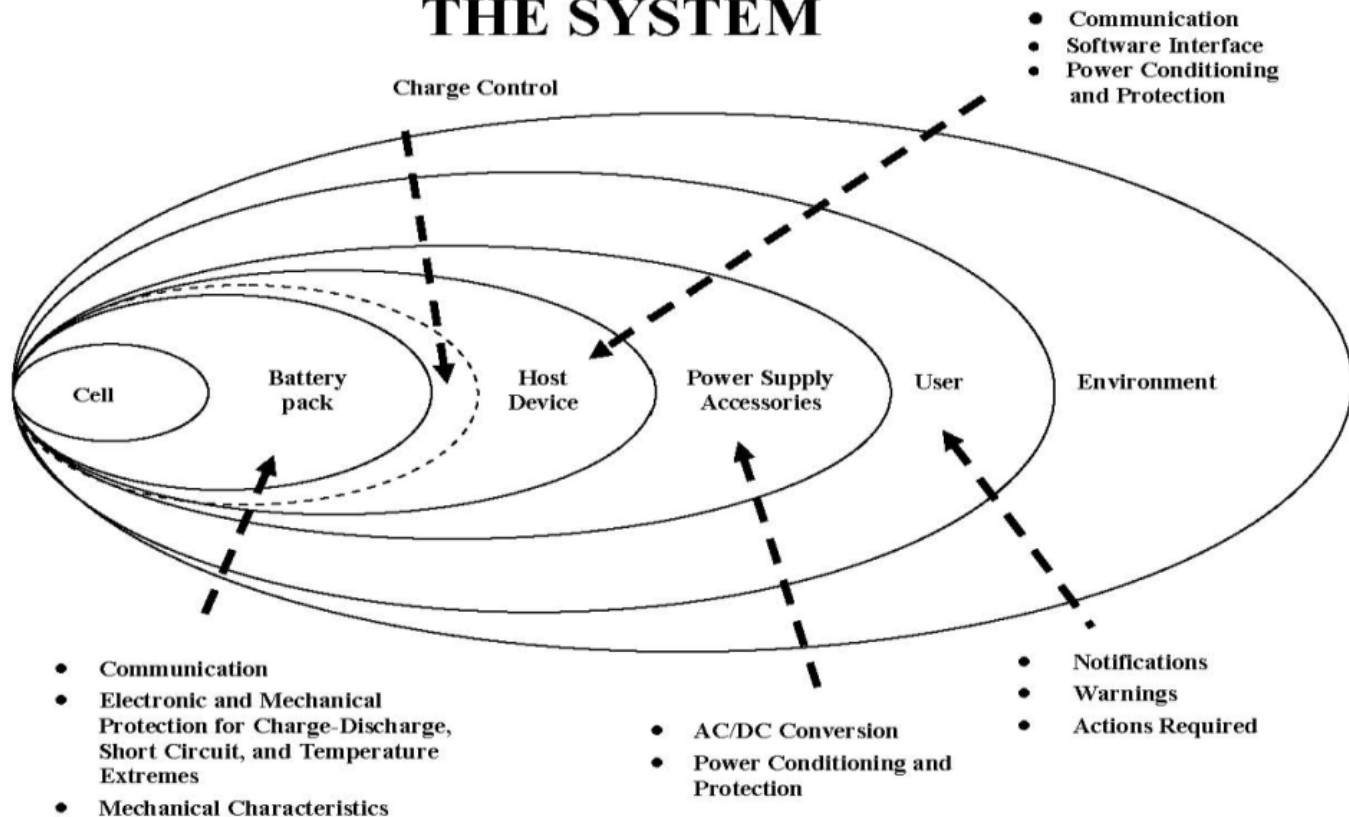
Outline

- Update on Compliance Recalls and Incident Data
- **Review of Emerging Hazards and Technology**
- Summary of Voluntary Standards Activities
- Research Testing and Data Findings



Emerging Battery Hazards – System Approach

THE SYSTEM



Source: IEEE 1725 - 2011



Emerging Battery Hazards

Technical Gaps are developing in voluntary standards due to:

- Thinner mobile devices
- Multifunctional mobile phone
- Longer battery life
- Non-removable battery pack
- High-power composition
- Fast and/or wireless charging
- Power-bank technology
- Temperature management
- Manufacturing/assembly process



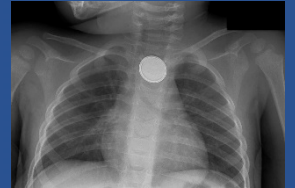
Impact of Design on Safety

Compact designs may be aesthetically pleasing and increase battery capacity. However, a tradeoff exists for safety-related thermal expansion/cell pressure buildup



Emerging Technologies

- Internet-connected products
 - Safety vs. Security
 - Improper software updates
- Wearable Technologies
 - Allergic reactions to materials
 - Chemical burns from exposed contacts
 - Coin cell ingestion hazard/secured battery compartments



Source: Google Images



Outline

- Update on Compliance Recalls and Incident Data
- Review of Emerging Hazards and Technology
- *Summary of Voluntary Standards Activities*
- Research Testing and Data Findings



Relevant Voluntary Standards

Portable Applications

- UL 2054 – Household/Commercial Batteries
- UL 1642 – Lithium Batteries
- UL 2056 – Power Banks
- UL 8139 – Electrical Systems for e-Cigarettes

Motive/Transportation Applications

- ANSI/UL 2271 – Light EV Batteries
- ANSI/UL 2580 – EV Batteries
- ANSI/UL 2272 – Electrical Systems for Personal e-Mobility Devices
- UL 2849* – e-Bikes, e-Scooters, e-Motorcycle
- UL 3030* – UAVs / Drones

* Outline of Investigation



Relevant Voluntary Standards

Stationary Applications

- ANSI/UL 1973 – Stationary Batteries
- ANSI/UL 9540 – Energy Storage Systems
- ANSI/UL 1989 – Standby batteries

Multi-use

- ANSI/UL 2743 – Portable Power Packs
- UL 2595 – General Requirements for Battery-Powered Appliances
- UL 60745-1 – Hand-Held Motor-Operated Electric Tools
- UL 62841-1 - Electric Motor-Operated Hand-Held Tools, Transportable Tools and Lawn and Garden Machinery



CPSC Battery Project Scope

CPSC staff addressing hazards associated with high energy density batteries in consumer products (Lithium-ion batteries) through:

- Enforcement, voluntary and mandatory standards work, import surveillance and compliance, and industry, interagency, and intergovernmental cooperation; and
- Assessment of potential hazards associated with manufacturing technologies, safety features/circuits, packaging, charging features and end- product system integration issues.



Batteries Web page at cpsc.gov

- List of voluntary standards
- CPSC staff activities and recommendations
- Safety Alerts
- Voluntary standards and code activities
- CPSC staff reports, memoranda, and contracts
- Contact information



FAA Reauthorization Act 2018

HR 302 Section 333

- Working Group – DOT, CPSC, FDA, NIST
- Safer battery technology
- Improve safety of LIB products in manufacturing, use, and shipping
- 12 months to make recommendations

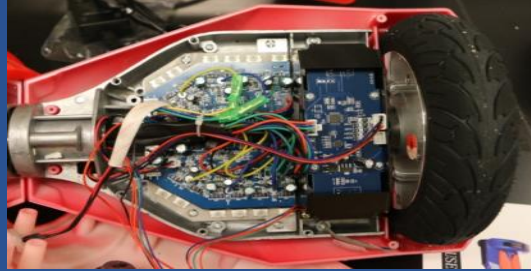
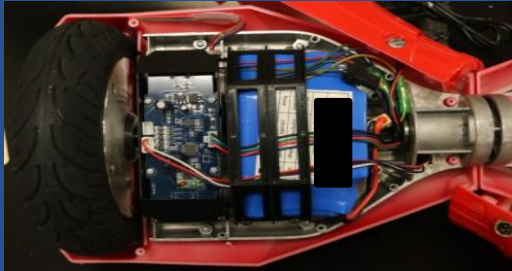
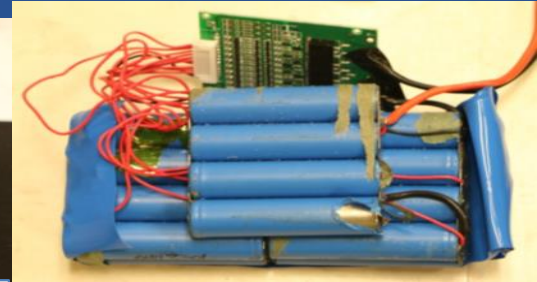


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Self-Balancing Electric Scooters or Hoverboards



Incidents from Self-Balancing Electric Scooters or Hoverboards



Incidents from Self-Balancing Electric Scooters or Hoverboards

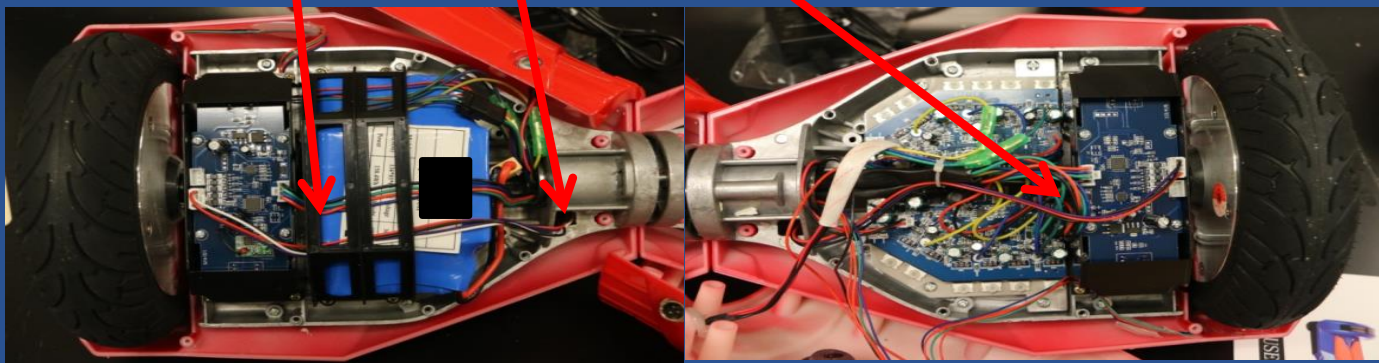
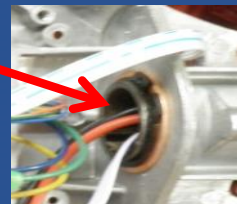
- Over 330 fire incidents since 2015, over \$9M in property damage
 - Incidents occurred in 43 states
 - During and after charging
 - During and after riding
- 5 Deaths – 2 battery-related fires (3 victims; 2 young girls, 1 elderly woman), 2 fall deaths
 - Estimate over 70,000 Emergency Room Visits
 - ~90% from falls, *e.g.*, sudden stops and starts
 - ~15% head injuries
 - ~50% arm injuries
 - ~40% fractures
 - ~30% sprain/abrasions



Internal Wiring

Wiring throughout hoverboard should follow recommended practices:

- Protective wire sheathing throughout pivot
- Casting deburred to prevent short circuits
- Securing loose wires
- Routing wires to prevent stress and cold flow



Hoverboard Evaluation Results

- Inadequate Battery Management System – Failed protective circuit safety analysis
- Inadequate cells (pack) for system loading
- Cells not certified to voluntary standards
- Battery chargers not certified to appropriate standards, UL 1310, UL 1012, or UL 60950-1
- Wiring improperly secured and protected in the pivot base, exposed connections
- > 500,000 units recalled

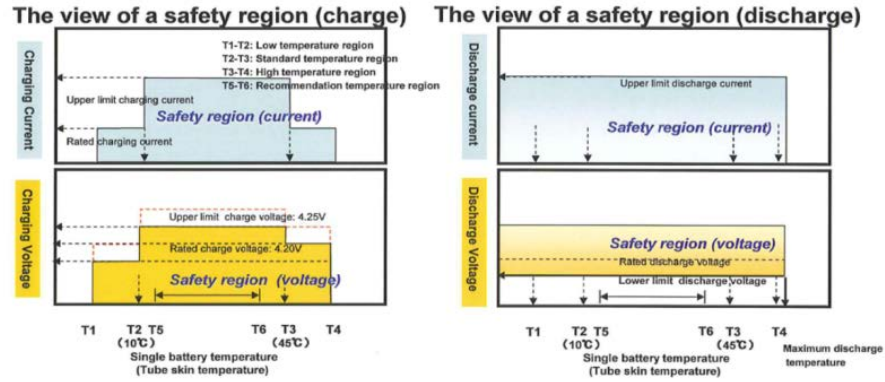


Hoverboard Voluntary Standards – Staff Participation

- UL 2272 - Outline of Investigation for Electrical Systems for Self-Balancing Scooters (January 2016)
- UL 2272 - Electrical Systems for E-Mobility Devices (First Edition, November 2016; revised, February 25, 2019); covers the electrical system –cells, pack, charger, and the entire product as a system
- ASTM International working on requirements for mechanical safety



Managing Voltage, Current, and Temperature Safely



Temperature domain	- T1	T1-T2	T2-T5	T5-T6	T6-T3	T3-T4	T4-
Capacity	Small	Design center value			Almost similar		
Characteristic	×	△	○	◎	○	△	×
Safety	×	○	○	○	○	○	×

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Source: Japan Electronics and Information Technology Industries Association and Battery Association of Japan
http://home.jeita.or.jp/page_file/20110517171451_cub9MvYFEh.pdf



Manage Voltage, Current and Temperature*

- Max charge voltage - 4.2V
- Min discharge voltage ~2.75V
- Max charge current C – capacity in A
- Max discharge current 2C or specified rate
 - 8.8A (2C) vs. 20A (5C - high discharge)
- Charge temperature - 0 to 45 °C
- Use temperature - 0 to 60 °C

*Values dependent on cell and chemistry

Source: Japan Electronics and Information Technology Industries Association and Battery Association of Japan

http://home.jeita.or.jp/page_file/20110517171451_cub9MvYFEh.pdf

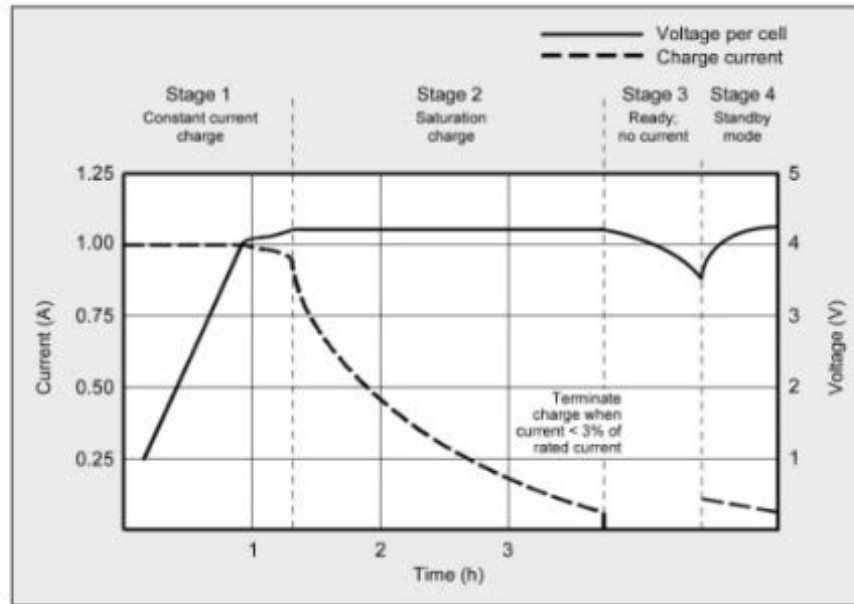


Manage Additional Charging Parameters

- Maintain balanced cells in multi-cell packs
- Disable charging if cell surface temperatures are $> 45\text{ }^{\circ}\text{C}$
- Disable charging or initiate pre-charge charging rate if cell is below 3 V
- Disable charging when charge current drops to .05C (no trickle charging)



Managing Charge Parameters Safely



Stage 1
Voltage rises at
constant current

Stage 2
Voltage peaks,
current decreases

Stage 3
Charge
terminates

Stage 4
Occasional
topping charge

Figure 1: Charge stages of lithium-ion. Li-ion is fully charged when the current drops to a set level. In lieu of trickle charge, some chargers apply a topping charge when the voltage drops.

Courtesy of Cadex

*Source:
http://batteryuniversity.com/learn/article/charging_lithium_ion_batteries



Interagency Effort to Improve Voluntary Standards

- Evaluating different mitigating techniques of cell-to-cell propagation in e-mobility device battery packs by triggering a thermal runaway condition on a single 18650 cell
- CPSC Interagency Agreement Work with Naval Surface Warfare Center – Carderock Division

NSWCCD Researchers:

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Thomas L. Jiang, Ph.D.

Jonathan K. Ko, Ph.D.

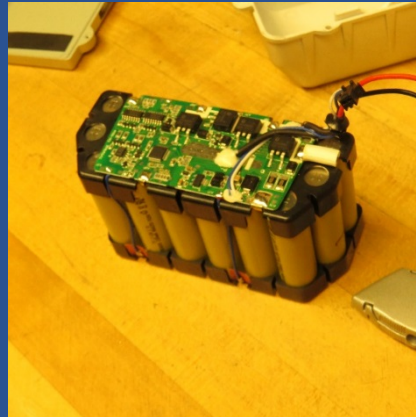
Gordon H. Waller, Ph.D.



Specific Types of Packs Evaluated (18650 cells)

Commercial Packs:

- Aluminum enclosure in 10S2P configuration
- 10S2P configuration w/o Aluminum Enclosure
- Plastic enclosure in 10S1P configuration



Packs Evaluated (cont'd)

Custom Packs:

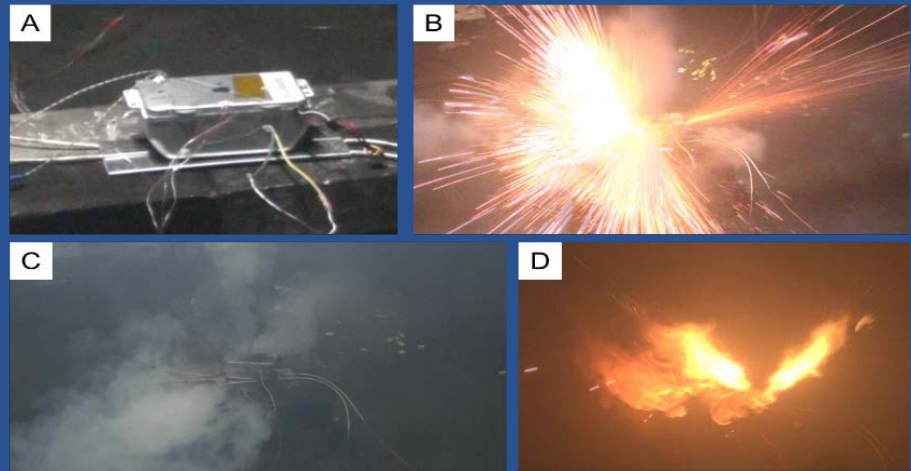
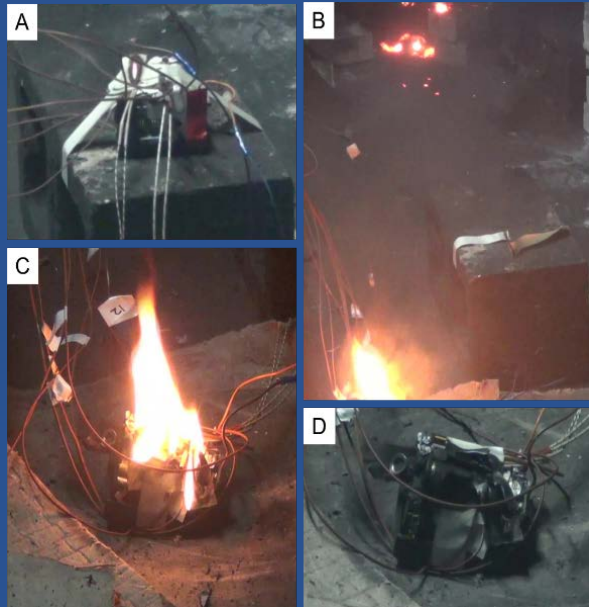
- Baseline - 10S1P without air gaps (closely constructed, left photo)
- Custom 10S1P with 3 commercially available mitigation materials (center 3 photos)
- Air gap as a standalone mitigation technique (right photo)



Test Results – Main Points

Commercial packs:

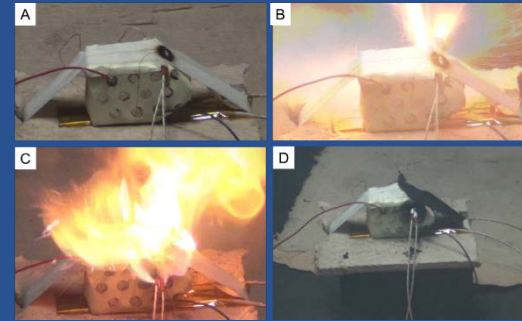
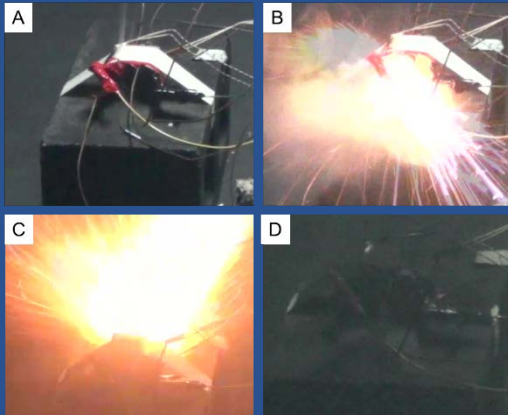
- All packs showed signs of thermal cell-to-cell propagation
- Aluminum case did not prevent cell-to-cell propagation



Test Results (cont'd)

Custom packs:

- The air gap and the fiber insulating wrapped packs showed minimal differences in mitigating thermal runaway
- For the other two commercially available materials, the trigger cell initiating thermal runaway, was delayed



Thermal Abuse Results Table

Pack ID	Time and T _{max} @ OCV drop	Time and T _{max} @ TR	Propagation?
Pack A1	17 min., 232 °C	30 min., 385 °C	N
Pack A2	26 min., 160 °C	33 min., 266 °C	N
Pack B1	57 min., 265 °C	57 min., 265 °C	Y
Pack B2	44 min., 60 °C	44 min., 60 °C	N
Pack B3	No OCV drop	49 min., 300 °C	N
Pack C1	27 min., 119 °C	35 min., 165 °C	Y
Pack C2	26 min., 142 °C	35 min., 201 °C	Y
Pack D1	38 min., 92.5 °C	44 min., 141 °C	Y
Pack D2	32 min., 100 °C	38 min., 152 °C	N
Pack E1	33 min., 114 °C	97 min., 149 °C	N
Pack E2	27 min., 117 °C	85 min., 168 °C	N
Pack E3	20 min., 105 °C	23 min., 162 °C	Y
Pack F1	60 min., 92.5 °C	117 min., 138 °C	Y
Pack F2	77 min., 81 °C	115 min., 101 °C	N
Pack G1	37 min., 141 °C	37 min., 168 °C	Y
Pack G2	23 min., 143 °C	65 min., 217 °C	Y



CPSC Suggested Practices for Lithium Battery Products

- Design and assembly using high quality cells
 - conform with applicable voluntary standards
 - suitable for the application and intended loads
 - in collaboration with cell and battery pack manufacturers
 - manufactured to best quality control processes
 - certified cells
 - build consistently with proper quality and safety
 - maintain quality and configuration control
 - assess impact of material or component substitutions
- Proper warning labels inform/educate users of potential hazards and to closely follow instructions for use
- Third-party certification from an accredited laboratory
- Continuously update product safety standards



Questions?

Contact Us:

- Electrical Program Area Risk Manager: Douglas Lee, dlee@cpssc.gov
- Materials Engineer: Dr. Yeon Seok Kim, ykim@cpssc.gov
- Electrical Engineer: Jay Kadiwala, Esq. jkadiwala@cpssc.gov



**Appendix B: CPSC Presentation – Lithium-Ion Battery Safety Standards
for Consumer Product Import into the United States (*presented to retail
buyers in China and South Korea*)**

U.S. Consumer Product Safety Commission



Lithium-Ion Battery Safety Standards for Consumer Product Import into the United States

May 16, 2017
Shenzhen, China

This presentation was prepared by CPSC staff, has not been reviewed or approved by,
and may not reflect the views of, the Commission.

Outline

Part 1: Data

- Basics on CPSC Databases
- Battery Incident Data
- Recalls

Part 2: Lithium-Ion Battery-Powered Product Case Studies

- No Product Standard (Before UL 2272) – Electric Scooters/Hoverboards
- Well-Developed Standards – Cell Phones and Laptops
- Lessons Learned – System Safety



Outline

Part 1: Data

- Basics on CPSC Databases
 - Electrical Product Safety
 - CPSC Risk Mitigation
- Battery Incident Data
- Recalls

Part 2: Lithium-Ion Battery-Powered Product Case Studies

- No Product Standard (Before UL 2272) – Electric Scooters/Hoverboards
- Well-Developed Standards – Cell Phones and Laptops
- Lessons Learned – System Safety



Electrical Product Hazards

- Electricity is a powerful, useful energy source that is potentially hazardous.
- Product failures or misuse can cause fires, electric shock, thermal burns (from exposure to hot surfaces), chemical burns (from batteries), injuries (lacerations from moving parts) or loss of critical function (a smoke alarm not signaling a fire).
- Equipment that generates, distributes, or uses electrical energy should be compliant with standards and installed according to applicable electrical codes to mitigate safety risks.



Electrical Product Hazards in U.S. Homes

CPSC staff est. average from 2011 to 2013:

- 43,400 structure fires from electrical equipment per year
 - 420 deaths, 3,000 injuries, & \$1.17 billion in property losses
 - Fires attributed mostly to:
 - Electric cooking equipment
 - Electrical distribution systems
 - Electric heating and cooling equipment

- From 2007 to 2009: est. average 70 product-related electrocutions per year



Electrical Product Hazard Prevention Strategies

CPSC staff promotes electrical safety through a multipronged approach

- Supporting improvements to voluntary standards/codes
- Disseminating safety information to consumers
- Creating and enforcing technical regulations and bans
- Recalling products with defects - identifying hazards through surveillance activities



Voluntary Consensus Standards

- Electrical product safety heavily relies on compliance with voluntary industry-consensus standards.
 - Most electrical product safety standards have been developed and maintained under the auspices of Underwriters Laboratories (UL). Other standards developers for electrical product safety include the Institute of Electrical and Electronics Engineers (IEEE) and the National Electrical Manufacturers Association (NEMA)



Technical Regulations

Regulatory process can be started by vote of the Commission or by a petition from an interested party

CPSC statutes specify that voluntary standards should be relied upon. However, a regulation may be issued if:

the current voluntary standard does not adequately reduce the risk

or

there is not substantial compliance.



Technical Regulations – “15J” Rules

- Takes an “observable characteristic” from a consumer product which has substantial compliance with the voluntary standard to reduce the hazard.
- Noncompliance results in automatic status as a “substantial product hazard.”
- Products that don’t comply with a 15J Rule won’t be allowed into the United States



Electrical Product Technical Regulations

- 16 CFR 1505 – Requirement for electrically operated toys or other electrically-operated articles intended for use by children



- 16 CFR 1204 - Safety Standard for Omnidirectional Citizens Band Base Station Antennas

15(j) Rule

- 16 CFR 1120.3(a) – Household and commercial handheld hair dryers must have an integral immersion protection circuit interrupter plug (as per UL 859 and UL 1727)
- 16 CFR 1120.3(c) – Seasonal and decorative lighting products must meet the minimum wire size requirements of UL 588, have sufficient strain relief and include integral overcurrent protection.
- 16 CFR 1120.3(d) – Extension Cords must meet the minimum wire size requirements of UL 817, have sufficient strain relief, be properly polarized and indoor-use cords must have outlet covers while outdoor-use cords must be jacketed.



Seasonal and Decorative Lighting Products



Lighting Products - Outside the Scope



Lighting Products -Three Observables

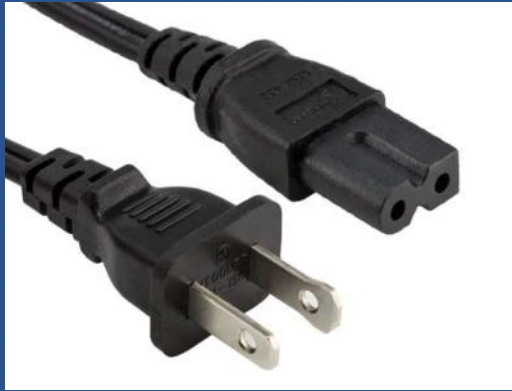
- Overcurrent Protection (a.k.a. fuse or fuses)
- Wire Size
- Strain relief



Extension Cords



Extension Cords - Outside the Scope



Extension Cords – Five Observables

- Minimum wire size
- Sufficient strain relief
- Proper polarization
- Proper continuity
- Protective feature (outlet covers or jacketed cord)



Voluntary Consensus Standards Third Party Certification

- CPSC's regulations do not require third party certification for electrical products (except for electric toys), but there is a high rate of voluntary compliance.
 - Many retailers will only sell electrical products if they have been third party certified.
 - Some states and municipalities require certification for all electrical products to be sold in those jurisdictions.
 - The Occupational Safety and Health Administration (OSHA) requires certification for electrical products used in the workplace.



CPSC staff strongly recommends that manufacturers or exporters/importers seek third party certification for their electrical products as a means of hazard mitigation.



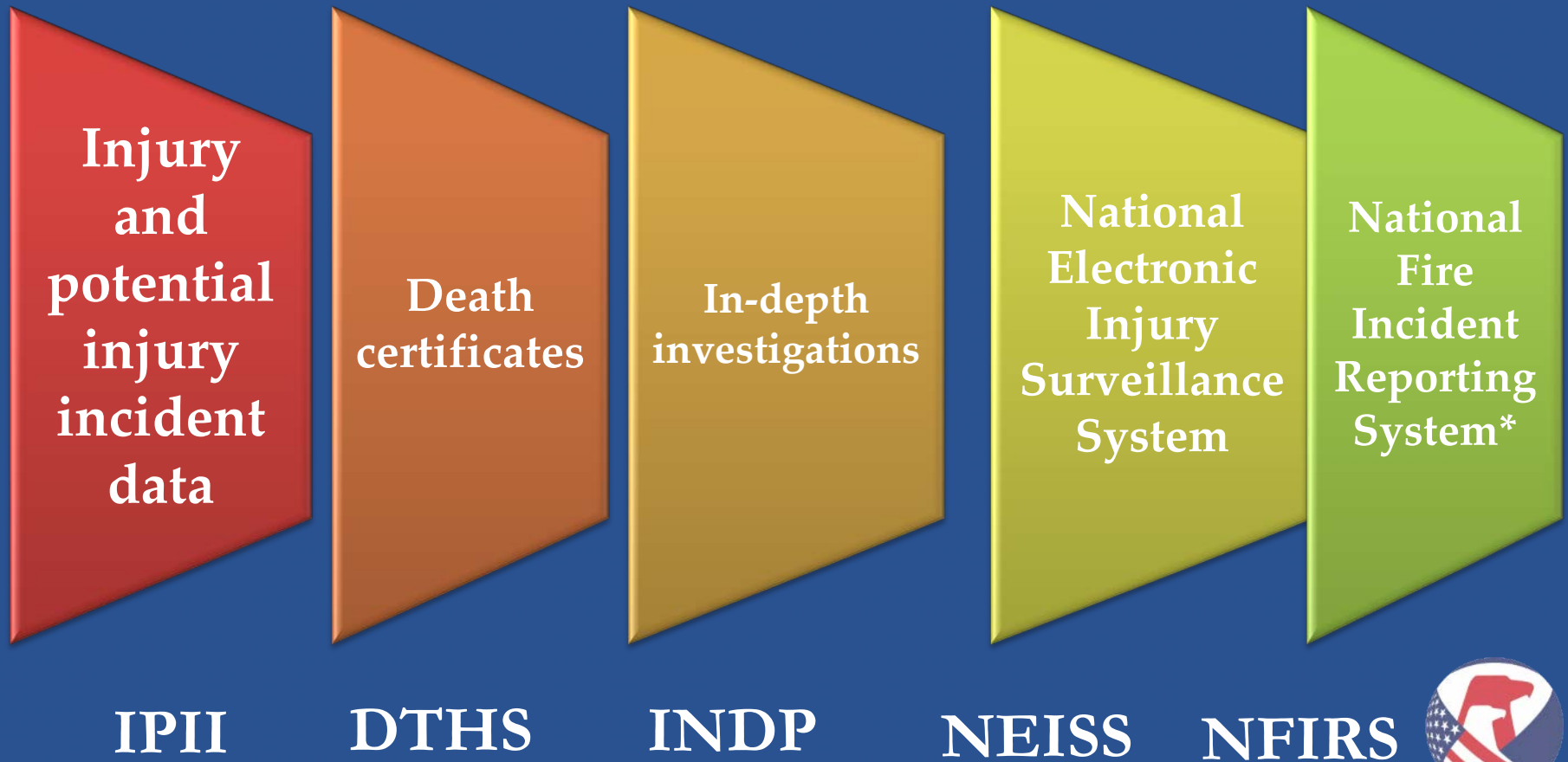
Voluntary Consensus Standards

- Staff actively participates in the process of maintaining the standards by addressing emerging hazards through development and adoption of new or modified requirements.
- This is an ongoing process that begins with reviewing incident information from CPSC's data collection systems.



CPSC Data Collection Systems

Staff learns about product-related incidents from five databases



*NFIRS is operated by the United States Fire Administration



DEATH CERTIFICATES DATABASE (DTHS)

- Contracts with 50 states
- Purchase approximately 8,000 per year
- Time lag
- Daily review
- Analytical use



IN DEPTH INVESTIGATIONS DATABASE (INDP)

- Field Investigations
 - On site
 - Local-level collaboration
 - Medical examiner
 - Police
 - Fire
 - Sample collection opportunity
- Telephone Interviews

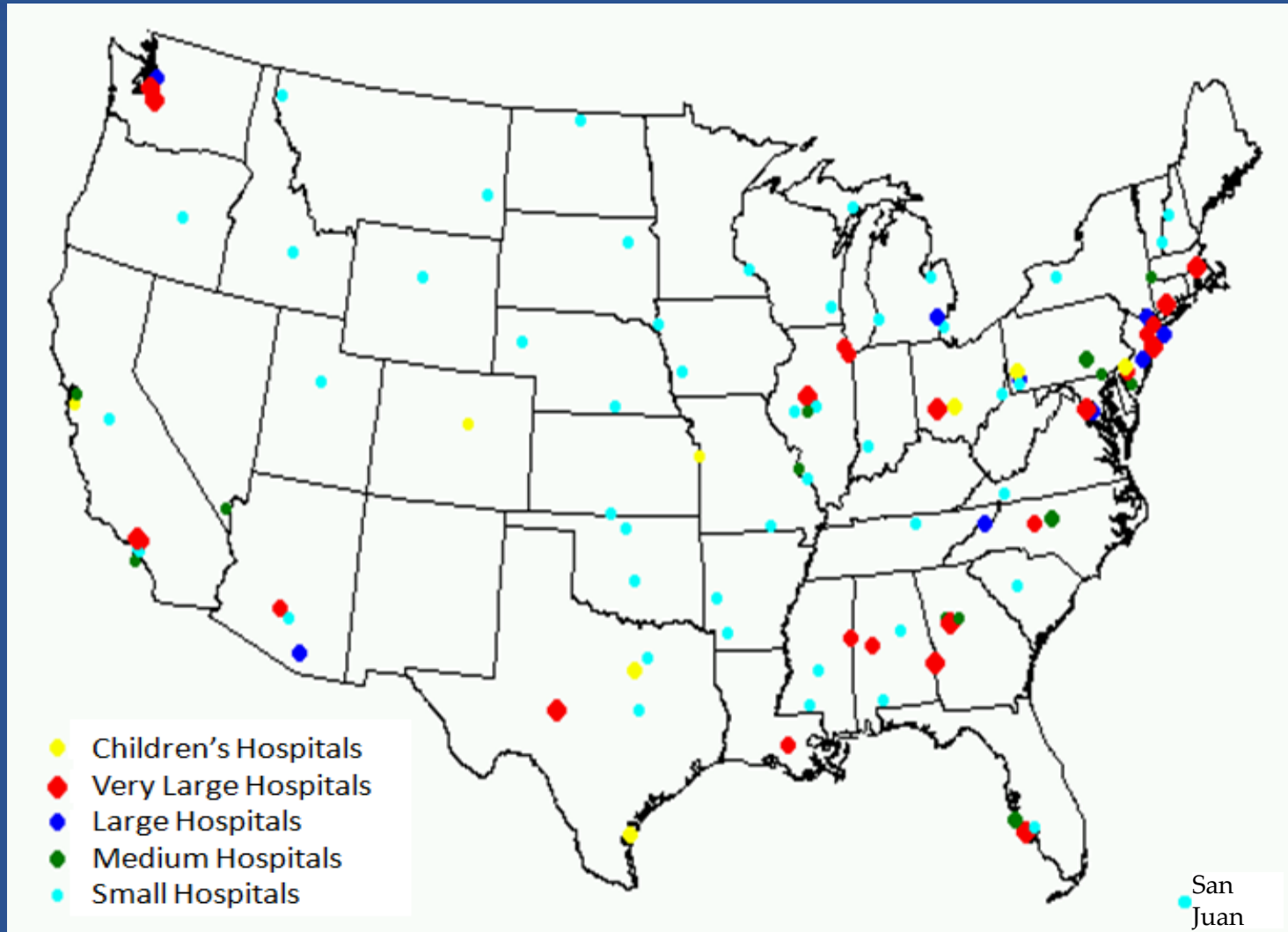


NATIONAL ELECTRONIC INJURY SURVEILLANCE SYSTEM (NEISS)

- National sample
 - Data collected from approximately 100 hospital emergency rooms around the country
 - Data weighted to provide consumer injury estimates nationwide
- Multilevel system
 - About 395,000 consumer product-related injury reports annually
 - About 300,000 other incident reports annually
- Data submitted daily by hospital coders
- Data available from 1980 to present

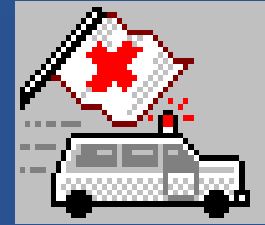


MAP OF NEISS HOSPITAL LOCATIONS

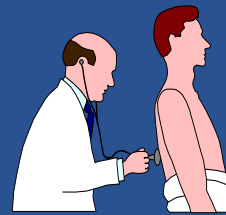


Why Emergency Department Data?

- Large numbers of injuries are treated.



- Data are already being captured in ED record on these cases.



- Hospitals have been very cooperative in supporting CPSC data collection activities.

- The information is timely.

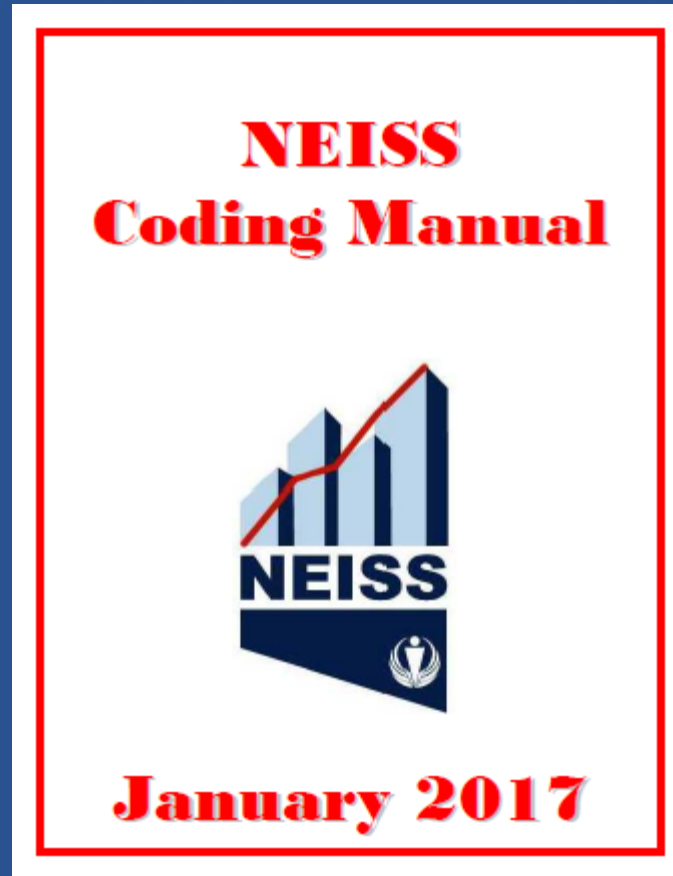


NEISS Surveillance Variables

- Treatment date
- Case number
- Age
- Sex
- Injury diagnosis
- Body part injured
- Disposition from ED
- Products involved (2)
- Locale
- Type/work-related
- Fire dept. involvement
- Intent
- Race/ethnicity
- Narrative (2 lines)



MORE INFORMATION?



<https://www.cpsc.gov/s3fs-public/2017NEISSCodingManualCPSCOnlyNontrauma.pdf>



Integrated Teams

- Chemical
- Children
- Combustion
- Electrical
- Fire
- Seniors and Mechanical



HAZARD IDENTIFICATION

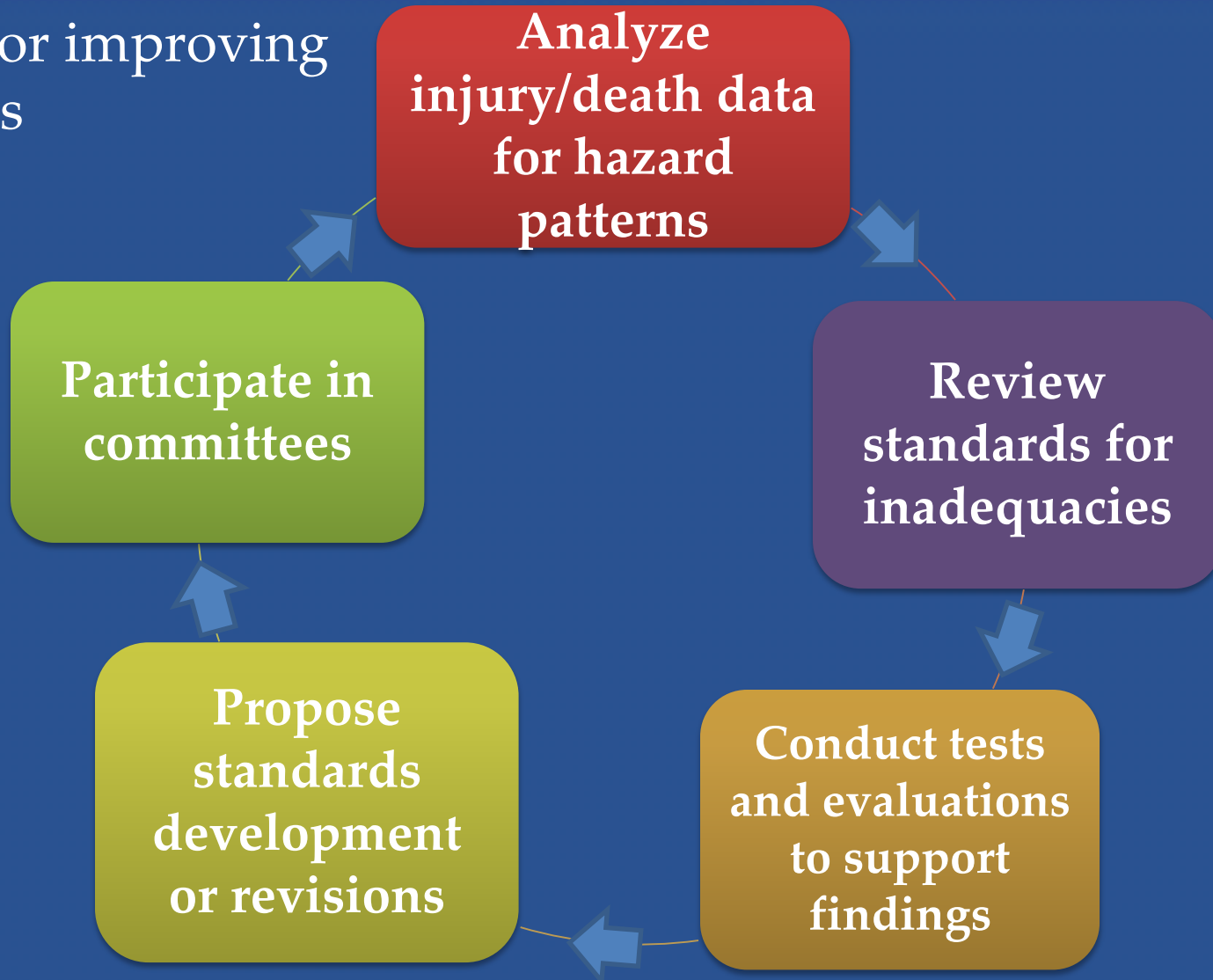
Integrated teams of experts review incidents and/or physical samples to:

- Identify hazards described
- Examine chain of events
- Review circumstances of incident, modes of failure
- Identify incident hazard patterns
- Screen for trends and emerging hazards
- Determine compliance with standards



Voluntary Standards - Staff Participation

Process for improving standards



Responsibility to Comply

- Compliance with applicable regulations, standards, and the *NEC* are highly effective ways to mitigate hazards from equipment that generates, distributes, or uses electrical energy.



- Importers, although reliant on foreign producers, are directly responsible for the safety of products they bring into the United States.



Responsibility to Comply

Manufacturers and importers should follow best practices to ensure that their products do not pose substantial risk of injury and need to be recalled.

- Comply with consensus standards and technical regulations
- Obtain third party certification for products
- Maintain quality and configuration control
 - Assess impact of material or component substitutions



Summary

Electrical safety requires diligence from producer to user.

- Electrical products should:
 - comply with relevant CPSC Technical Regulations
 - be designed and manufactured in accordance with applicable voluntary standards
 - have third party certification from an accredited laboratory
 - be built consistently and with proper quality and safety
 - have product safety standards that are continuously updated to address hazards identified by incident data



Outline

Part 1: Data

- Basics on CPSC's Databases
- **Battery Incident Data**
- Recalls

Part 2: Lithium-Ion Battery-Powered Product Case Studies

- No Product Standard (Before UL 2272) – Electric Scooters/Hoverboards
- Well-Developed Standards – Cell Phones and Laptops
- Lessons Learned – System Safety



CPSC Battery Project Scope

- Commission directed CPSC staff to:
 - Address hazards associated with high energy density batteries in consumer products (Lithium-ion batteries)
 - Efforts to include enforcement, voluntary and mandatory standards work, import surveillance and compliance, and industry, interagency, and intergovernmental cooperation
 - Project effort intended to address battery hazards by assessing manufacturing technologies, safety features/circuits, packaging, charging features and end-product system integration issues
- 2017 assessment will direct future projects/activities



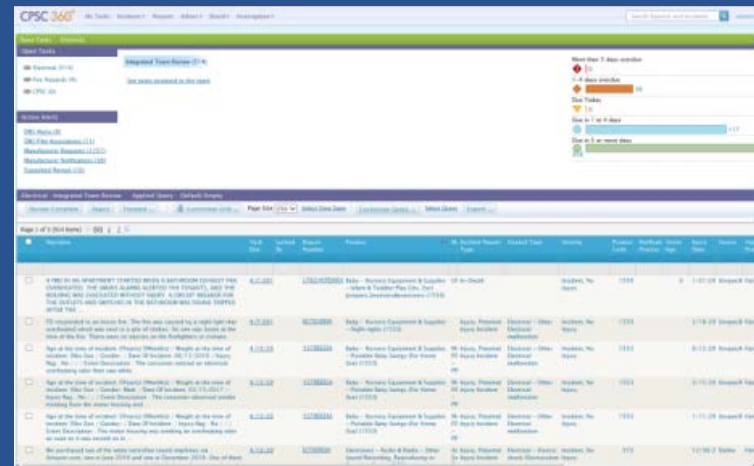
Relevant Voluntary Standards Activity

- Hoverboards/Electric Scooters - New Outline of Investigation (1/16), ANSI/CAN/UL 2272-16 *Electrical Systems for Personal E-Mobility Devices* (11/16)
- ASTM F963-16 Toy Safety (11/16) - CPSC Toy Regulation 4/30/17
- IEEE 1725-2011 Cellular Telephones - Certification and standard updates
- IEEE 1625-2008 Mobile Computing - Certification and standard updates
- Baby Monitors ASTM F2951-13 – Add battery requirements from ASTM F963 or UL 62368-1 requirements
- E-Cigarettes (FDA) – UL 8139 (3/17) *Outline of Investigation for Electrical Systems of Electronic Cigarettes*



Battery Incident Data

- Consumer Product Safety Risk Management System (CPSRMS) - Anecdotal Incident reports from public sources (NEISS and Compliance data removed)
- Searched Incident reports from 1/1/12 to 1/24/17 using Narrative field search terms:
LI-ION/LITHIUM/POLYMER/BATTER/CHARG
- Results: 21,687 incident reports; 483 primary product codes



The screenshot displays the CPSRMS (Consumer Product Safety Risk Management System) interface. At the top, there is a search bar and navigation options. Below the search bar, a table lists incident reports. The table has columns for 'Incident ID', 'Date', 'Status', 'Product Code', 'Product Name', 'Product Type', 'Product Category', 'Product Subcategory', 'Product Code', 'Product Name', 'Product Type', 'Product Category', 'Product Subcategory', 'Product Code', 'Product Name', 'Product Type', 'Product Category', 'Product Subcategory'. The table contains several rows of data, including incident IDs, dates, and product codes. A sidebar on the right shows a search filter for 'Incident Type' with a dropdown menu and a search button. The bottom of the screen shows a pagination bar with 'Page 1 of 2167 pages' and '21,687 records'.

Incident ID	Date	Status	Product Code	Product Name	Product Type	Product Category	Product Subcategory	Product Code	Product Name	Product Type	Product Category	Product Subcategory
123456789	1/1/12	Open	123456789	123456789	123456789	123456789	123456789	123456789	123456789	123456789	123456789	123456789
987654321	2/1/12	Open	987654321	987654321	987654321	987654321	987654321	987654321	987654321	987654321	987654321	987654321
567890123	3/1/12	Open	567890123	567890123	567890123	567890123	567890123	567890123	567890123	567890123	567890123	567890123
234567890	4/1/12	Open	234567890	234567890	234567890	234567890	234567890	234567890	234567890	234567890	234567890	234567890
890123456	5/1/12	Open	890123456	890123456	890123456	890123456	890123456	890123456	890123456	890123456	890123456	890123456



CPSRMS Summary (Top 30 Product Codes)

PROD	Hits	Product Description
884	10031	BATTERIES
557	3399	COMPUTERS (EQUIPMENT AND ELECTRONIC GAMES)
4062	2906	ELECTRIC WIRE OR WIRING SYSTEMS (EXCL PANELBOARDS RECEPT
550	2594	TELEPHONES OR TELEPHONE ACCESSORIES
883	1813	BATTERY CHARGERS
1394	1190	DOLLS, PLUSH TOYS, AND ACTION FIGURES
(blank)	1073	#N/A
5021	739	TOY VEHICLES (EXCLUDING RIDING TOYS)
821	548	AUTOMOTIVE TOOLS OR ACCESSORIES
4061	487	ELECTRIC OUTLETS OR RECEPTACLES
639	448	FLASHLIGHTS OR BATTERY-POWERED LANTERNS
1330	413	POWERED RIDING TOYS
5042	366	SCOOTERS / SKATEBOARDS, POWERED
1553	322	PORTABLE BABY SWINGS (FOR HOME USE)
546	315	STEREO OR HI-FI COMPONENTS OR ACCESSORIES
1550	315	INFANT & TODDLER PLAY CTRS, EXCL JUMPERS,BOUNCERS&EXERCISERS
1526	280	CRIB MOBILES OR CRIB GYMS
1807	278	FLOORS OR FLOORING MATERIALS
536	276	PHOTOGRAPHIC EQUIPMENT
1365	249	WATER TOYS
702	234	FIRE OR SMOKE ALARMS
676	163	RUGS OR CARPETS, NOT SPECIFIED
855	135	PORTABLE POWER DRILLS AND ACCESSORIES
4083	134	SURGE SUPPRESSORS OR POWER STRIPS
4039	124	OTHER ELECTRIC LIGHTING EQUIPMENT
573	118	OTHER SOUND RECORDING, REPRODUCING OR RECEIVING EQUIP.
278	108	ELECTRIC RANGES OR OVENS (EXCL COUNTER-TOP OVENS)
679	104	SOFAS, COUCHES, DAVENPORTS, DIVANS OR STUDIO COUCHES
1558	99	BABY BOUNCER SEATS (EXCL. JUMPERS)
5040	89	BICYCLES AND ACCESSORIES, (EXCL.MOUNTAIN OR ALL-TERRAIN)



CPSRMS Data

- Manually filter incidents categorizing
 - like products
 - battery capacity/size (if available)
- Risk: Fires, explosions, and overheating vs. smoke and melting
- Exclude:
 - Non-lithium-ion batteries
 - Charger (isolated from battery issue)
 - Cords (isolated from battery issue)
- Data are raw
 - Not for statistical analysis
 - Anecdotal
 - Duplicates



Laptop CPSRMS Incident Data

(2012-2017)

- Over 3000 incidents involving computer battery or charger or both
 - Fire, overheating, melting, smoking, or explosion
 - 30% mentioned battery
 - 75% mentioned charger or charging
 - Reviewing IDIs to determine cause of incidents



Cell Phone CPSRMS Incident Data

(2012-2017)

- Over 2000 incidents involving cell phone battery or charger or both
 - Fire, overheating, melting, smoking, or explosion
 - 30% mentioned battery
 - 80% mentioned charger or charging
 - Reviewing IDIs to determine cause of incidents



Power Bank CPSRMS Data

(2012-2017)

- Power Bank – Portable USB charger or back-up battery power
- Over 400 incidents involving power bank charging
 - Fire, overheating, melting, smoking, or explosion
 - Charging or charging another product
 - Reviewing IDIs to determine cause of incidents



CPSRMS Drone Data

(2012-2017)

- Over 200 incidents involving drones
 - Fire, overheating, melting, smoking, or explosion
 - Over 50% while charging
 - Over 100 injuries related to lacerations or contusions (NEISS Data)
 - Reviewing IDIs to determine cause of incidents
 - Although incidents are reported on CPSRMS, drones are not within CPSC jurisdiction



CPSC E-Cigarette Fire and Explosion Data (Food and Drug Administration Jurisdiction)

- Through 2016 – 34 Emergency room visits (NEISS*)
 - 29 Explosions, 5 Fires
- Location of Battery or E-Cigarette Device
 - 23 In pocket (19 Batteries), 4 In hand, 3 Near thigh, 2 In Face, 1 Near eye, 1 In car charger
- Injuries
 - 32 burns – 1 electrical, 4 chemical, and 27 thermal; 2 Lacerations
- Ages (16 to 57)
 - 11 Ages (16 to 24)
 - 12 Ages (25 to 34)
 - 8 Ages (35 to 44)
 - 3 Age 45 or older

*Data insufficient to generate national estimate



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- Basics on CPSC's Databases
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- **Recalls**

Part 2: Lithium-Ion Battery-Powered Product Case Studies

- No Product Standard (Before UL 2272) – Electric Scooters/Hoverboards
- Well-Developed Standards – Cell Phones and Laptops
- Lessons Learned – System Safety



Recalls of Lithium-ion Battery Products (2012-2017)

- 49 Recalls of Lithium-ion Battery-Powered Products

Product	# of Recalls	# Recalled
Hoverboard	11	502,200
Laptop	11	498,162
Flashlight/Lantern	3	18,305
Tablet	2	83000
Power Bank	4	211325
Charger	3	684007
Battery Backup	1	2500
Jumpstarter	2	14814
E-Bike	1	5000
UPS	1	2876
Cell Phone	1	1920927
Other*	9	289692
	Total	4,232,808

*Other products include baby monitor, gloves, hand warmers, RC car battery pack and wireless speakers



Recalls of Lithium-ion Battery Products (2012-2017)

- Recalls – 49
 - Products Involved – 4,232,808
 - Samsung Note 7s – 1,920,927
 - Electric Scooters – 500,000+
 - Ryobi Charger and Battery – 637,707
 - Laptop Computers – 368,299



Recalls of Lithium-ion Battery Products

- Root Causes
 - Battery Management System (BMS)
 - Cell Manufacturing quality control (QC)
 - Lack of system integration (Charger-BMS-Cells)
 - Non-Listed cells/systems
- Standards (voluntary or mandatory)
 - Addressable
 - Non-addressable



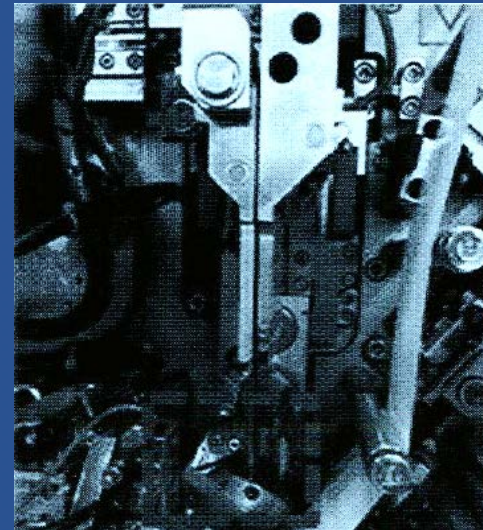
Reasons for Previous Recalls

- Battery Pack Design Problems
 - Lacks safety circuits
 - Lacks adequate (or any) overcharge/over-discharge protection
 - Lacks adequate physical protection
- Quality Control Problems in Cell Manufacturing
 - Improper placement of leads
 - Contaminants in cell
 - Uneven forming of cell
 - Welding sharp edges on tab (new)
 - Missing insulating tape on tab (new)



Cylindrical Cell Contaminant

- Iron (Fe) particle adhered to electrode
- Particle from moving chuck
- Chuck is used to position electrode for cutting
- Metallic particles can perforate separator and short electrodes in certain areas



Cylindrical Cell Contaminant Mitigation

- Root Cause: Chuck was repositioned improperly when interference occurred
- Correct alignment of chuck
- Track assembly line production from affected dates
- Limit scope of recalled products
- Implement process to control further issues with chuck alignment
- Reduce other metal-to-metal processes in cell manufacturing



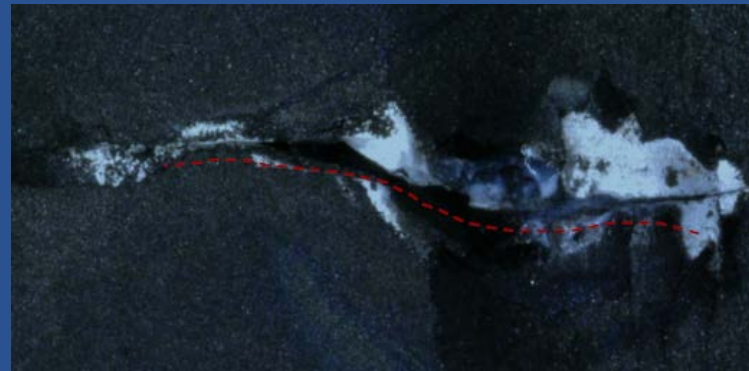
Contamination Mitigation

- Processes used to mitigate cell contamination
 - Magnets used to capture ferrous particles
 - Suction used to capture other particles
 - Air ventilation and filtration systems in production areas to minimize contaminants
 - Cell dissection to look for foreign particles
 - X-rays – non-destructive inspection for foreign particles and assembly anomalies
 - CT Scanner – more detailed non-destructive inspection



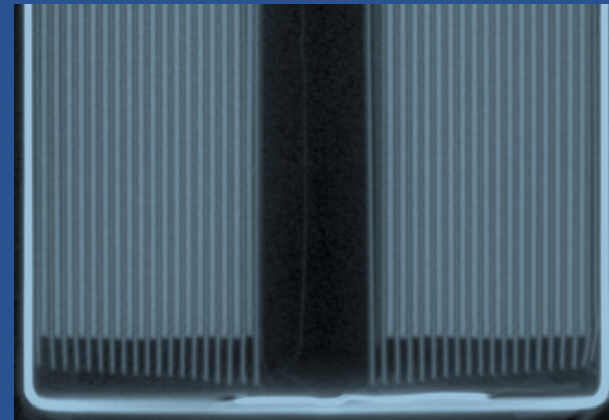
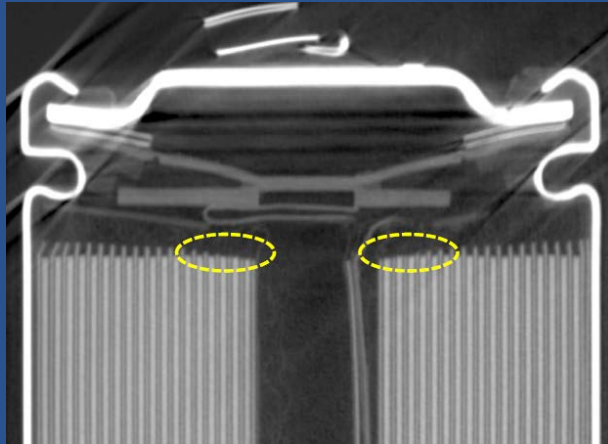
Physical Damage

- Damaged outer foil in polymer cell
- Causing internal soft short
- Visual inspections are needed to identify problems and initiate corrective actions before cells leave factory



Electrode Alignment

- Sufficient electrode overlap
- Mitigates risks of short circuit from lithium plating on edge
- Negative overlap $> 100 \mu\text{m}^*$



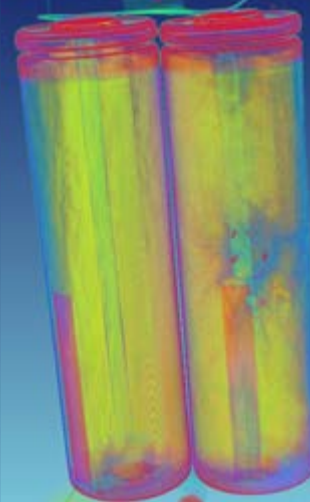
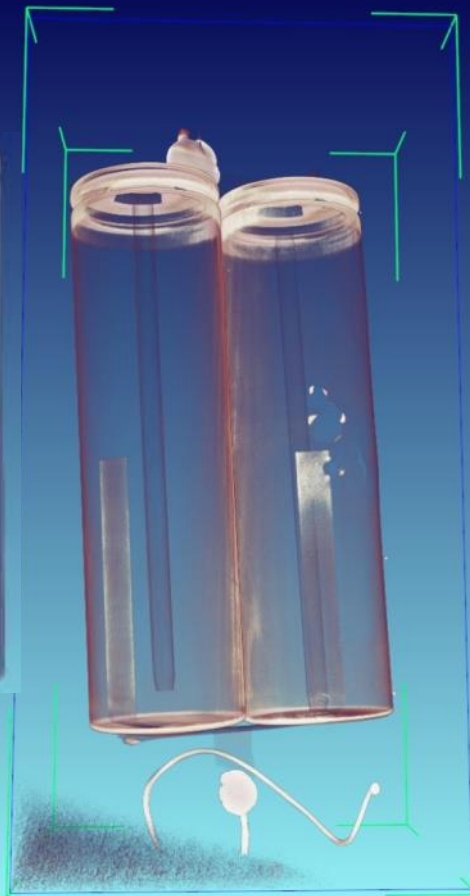
* IEEE 1625 (Laptops) and IEEE 1725 (Cell phones) standards



Internal Cell Faults



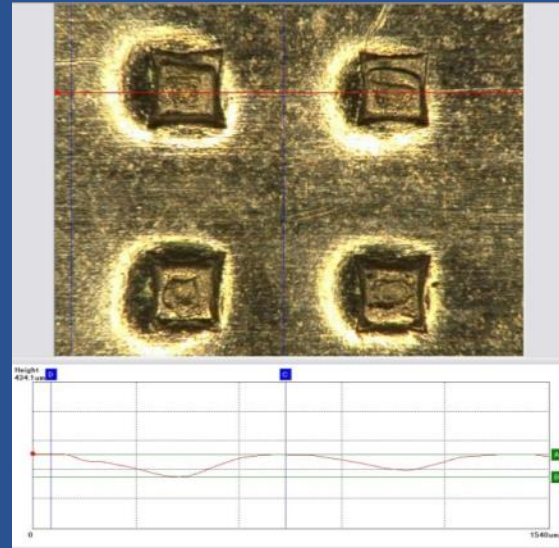
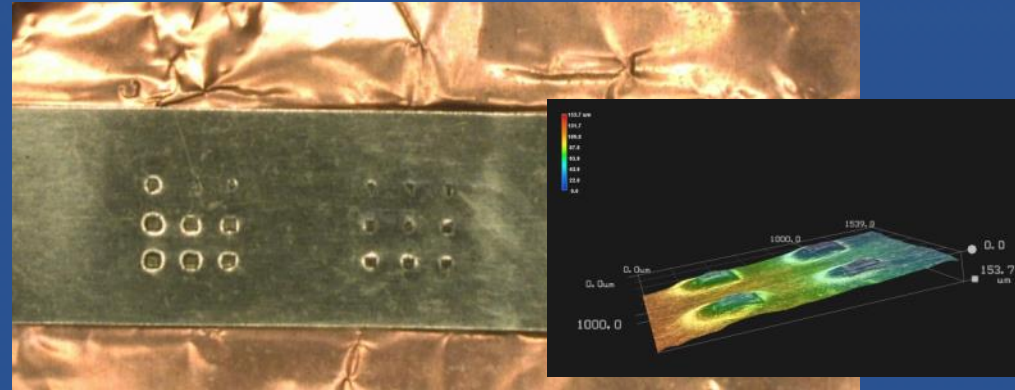
U.S. Consumer Product Safety Commission
National Product Testing and Evaluation Center
Rockville, Maryland



- CT Scans and X-rays used to evaluate internal cell faults



CPSC Staff Ultrasonic Welding Evaluation – Tabs

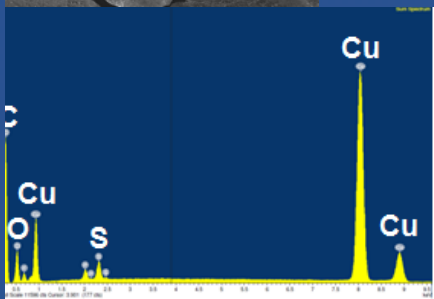
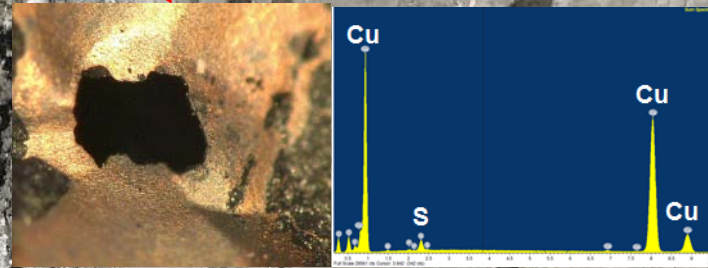
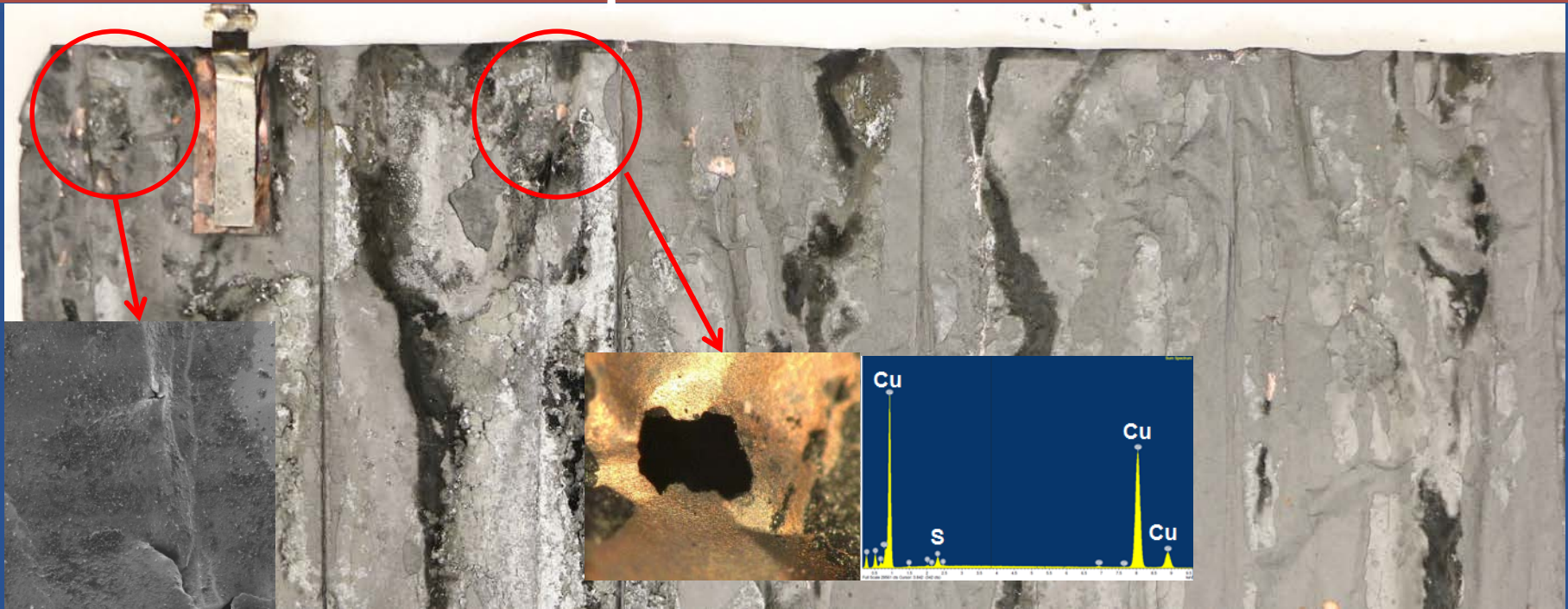


Each Layer thickness

- Separator = 10 ~ 20 μm
- Tabs = 20 ~ 80 μm
- Cu and Al foil = 10 ~ 20 μm
- Coatings = 40 ~ 60 μm



CPSC Staff Thermal Runaway Sample Evaluation



- Evaluation of potential internal shorts via high-powered optical microscope and SEM/EDS
- Any hole or anomalies are evaluated.
- A part of copper foil can be consumed during thermal runaway or initial internal shoring.



Outline

Part 1: Data

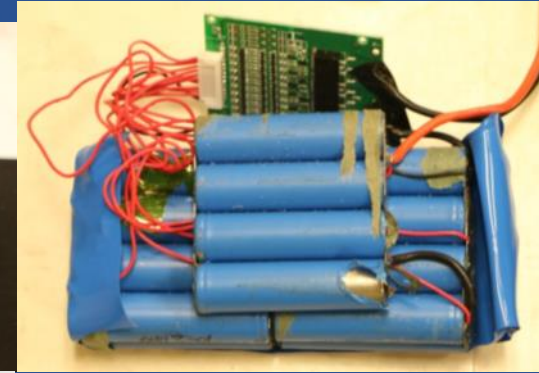
- Basics on CPSC's Databases
- Battery Incident Data
- Recalls

Part 2: Lithium-Ion Battery-Powered Product Case Studies

- **No Product Standard (Before UL 2272) – Electric Scooters/Hoverboards**
- Well-Developed Standards – Cell Phones and Laptops
- Lessons Learned – System Safety



Self-Balancing Electric Scooters or Hoverboards



Incidents from Self-Balancing Electric Scooters or Hoverboards

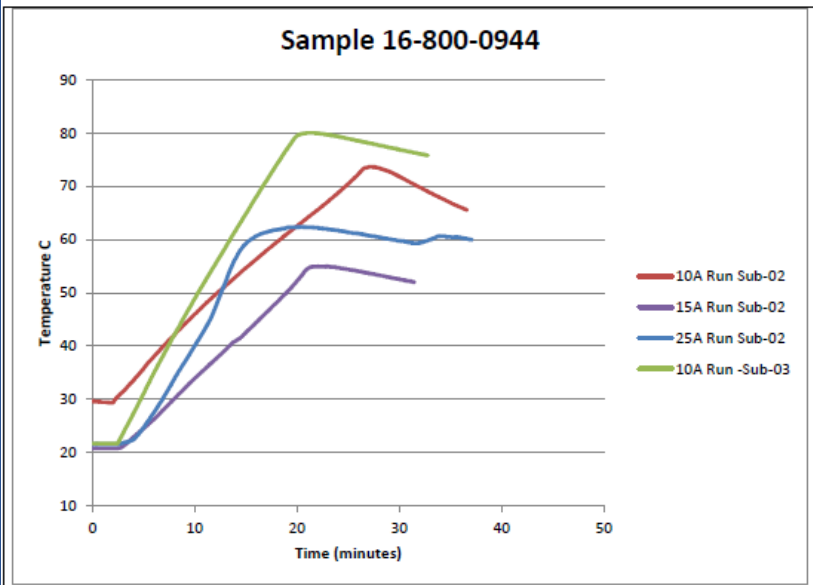


Incidents from Self-Balancing Electric Scooters or Hoverboards

- Over 165 fire incidents, causing over \$3M in property damages
 - Incidents occurred in 38 states
 - During and after charging
 - During and after riding
- 3 Deaths – 1 fire (2 victims, young girls), 1 fall (MVA death excluded)
- Estimated over 10,000 Emergency Room Visits
 - ~90% from falls, e.g. sudden stops and starts
 - ~15% head injuries
 - ~50% arm injuries
 - ~40% fractures
 - ~30% sprain/abrasions



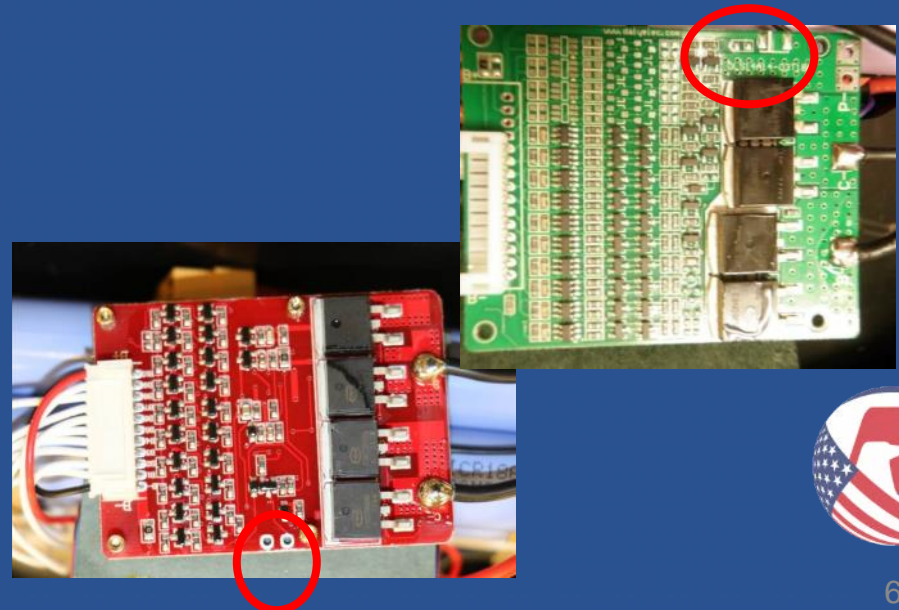
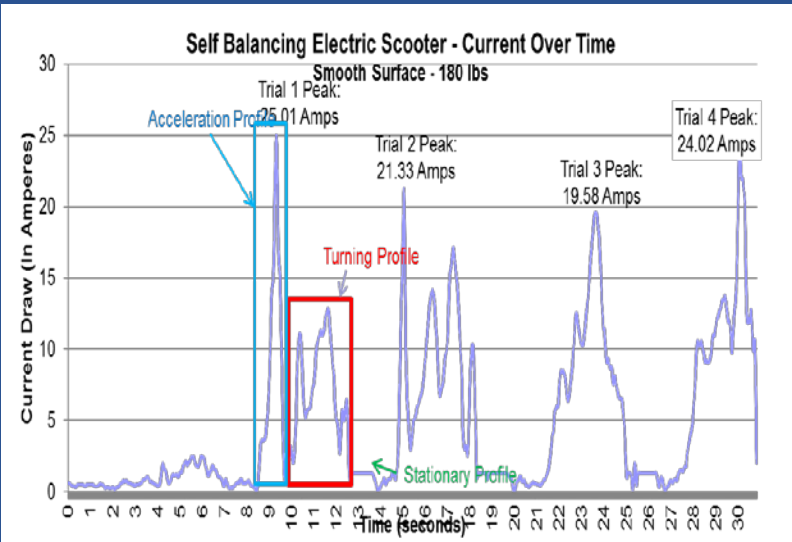
Temperature Management Sensor Not Used



8	Temperature	Operating Temperature Range	-40 ~ +85°C
		Storage Temperature Range	-40 ~ +125°C
		Discharging Temperature protection	65±5°C

Size: L63*W55*T7mm

B + / P + = Charge + / Discharge +
C - = Charge - / Discharge -
P - = NC



Staff Hoverboard Assessment

- Staff thoroughly tested and analyzed units on market, found that many used uncertified lithium-ion cells/chargers and did not follow typical safe cell operating practices to protect against operation at excessive temperatures, overcharging or over-discharging.
- Units posed fire hazard.
- Fire incident units exhibited signs of thermal runaway leading to catastrophic failure of the entire battery pack



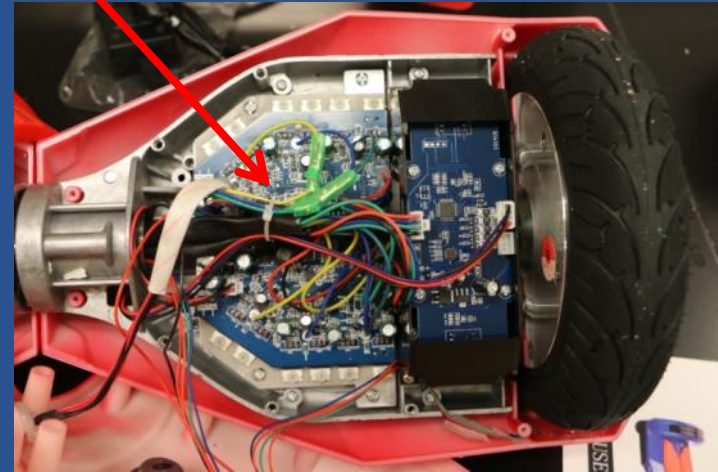
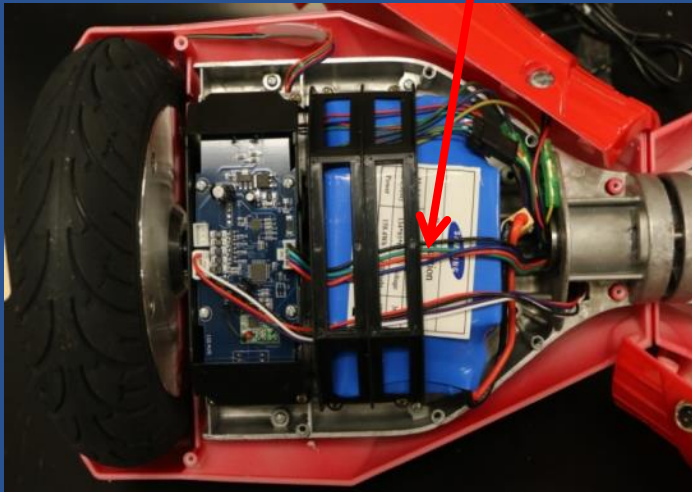
Hoverboard Evaluation Results

- Inadequate Battery Management System – Failed protective circuit safety analysis
- Inadequate cells (pack) for system loading
- Cells not certified to standards to ensure cells are manufactured to best practices
- Battery chargers not certified to appropriate standard, UL 1310, UL 1012, UL 60950-1
- Wiring improperly secured and protected in the pivot base, exposed connections
- > 500,000 units recalled



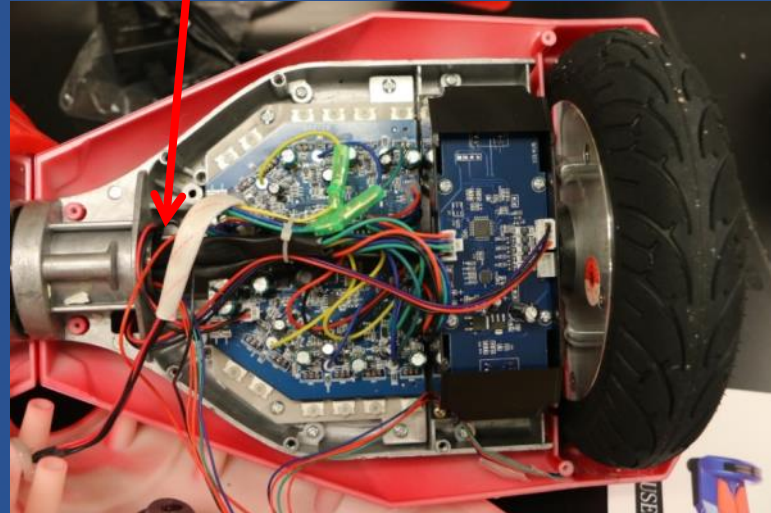
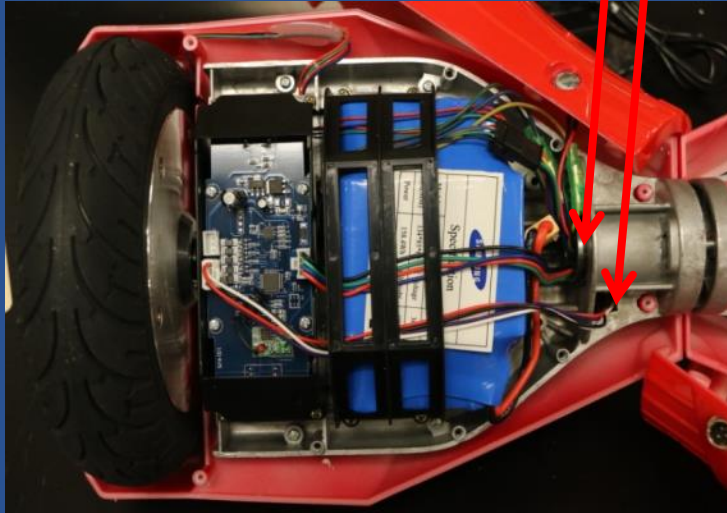
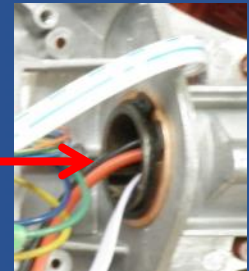
Internal Wiring

- Wiring throughout hoverboard should be using best practices
 - Securing loose wires
 - Routing wires to prevent stress and cold flow



Internal Wiring

- Wiring throughout hoverboard should be using best practices
 - Protective wire sheathing throughout pivot
 - Casting deburred to prevent short circuits



Hover Board Voluntary Standards – Staff Participation

- UL 2272 - Outline of Investigation for Electrical Systems for Self-Balancing Scooters (January 2016)
- UL 2272 - Electrical Systems for E-Mobility Devices (November 2016)
 - Covers the electrical system –cells, pack, charger, and the entire product as a system
- ASTM International working on requirements for mechanical safety



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- No Product Standard (Before UL 2272) – Electric Scooters/Hoverboards
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- Lessons Learned – System Safety



Well-Developed Standards

- Cell phones (IEEE 1725) and Laptops (IEEE 1625) are not immune to incidents



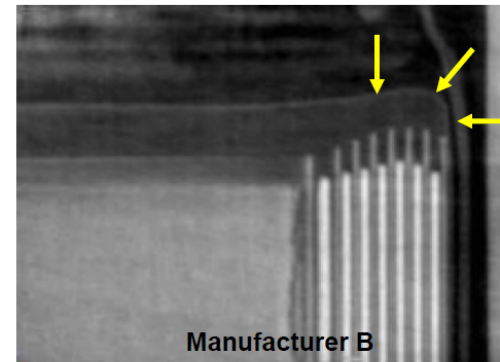
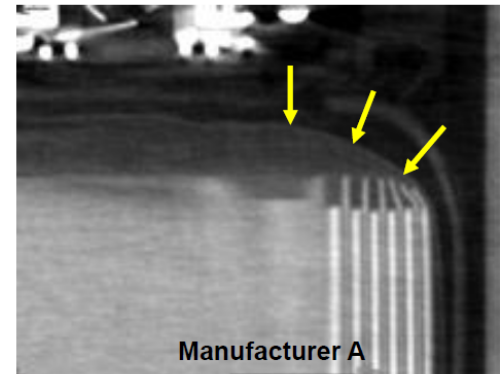
Source: Google images



Manufacturing Design Issue A*

Root Cause: Manufacturer A

- Based on the results of analysis and testing, the most likely root cause for the thermal failure of certain Manufacturer A cells was determined to be unintended damage to the negative electrode windings consistently in the corner of the cell closest to the negative tab
 - The unintended damage was present in all of the cells examined by Samsung and Exponent
 - The damage was caused by a cell pouch design that provided inadequate volume to accommodate the electrode assembly
 - The observed damage provides multiple potential routes to internal cell faulting and thermal failure with normal cycling, including compromise of the separator and lithium plating
- Exponent's initial analysis of cells from Manufacturer B showed no deficiencies in the pouch, design or manufacturing
 - Manufacturer B cells manufactured after our initial investigation was complete were shown to contain a distinctly different defect that was not present in the initial cells we investigated



Manufacturing QC Issue B*

Root Cause: Manufacturer B

- Based on the results of analysis and testing, the most likely root cause for the thermal failure of Manufacturer B cells was determined to be internal cell faulting between positive electrode tab welding defects and the copper foil of the negative electrode directly opposite the defective welds
 - Welding defects in some incident cells were found to be tall enough to bridge the distance to the negative electrode foil
 - Some cells examined were assembled without protective tape over the positive electrode tab, increasing the likelihood of an internal cell fault

Positive Tab



Negative Electrode
Opposite Positive Tab



IEEE 1725 Requirements Review and Staff Recommendations

- Cell core assembly
 - Corner clearance validation process
- Detection of damaged cores
- Cell Aging
- Testing procedures
- Dissection of cycled cells
 - verify 4 corners - radius (prismatic/polymer)
 - verify top and bottom of core (cylindrical)



IEEE 1725 Requirements Review and Staff Recommendations

- Cell Aging
- Dissection of cycled cells
 - (proposed) verify electrode tab welds
 - (proposed) verify insulation tape at tabs in key areas such as the electrode ends and radius of
 - (proposed) verify insulation tape at electrode ends
 - (proposed) verify insulation tape at radius



IEEE 1725 Requirements Review and Staff Recommendations

- User Interactions and Responsibilities (information to user)
 - (proposed) Remove from pants pocket when sitting
 - (proposed) Cases are recommended to protect the phone from physical damage
- (proposed) External forces requirement: drop, impact, and flexing test requirements
 - Dissection of tested units
- Global review to update referenced standards and technology changes



IEEE 1625 Requirements Review and Staff Recommendations

- Review IEEE 1625 changes to incorporate IEEE 1725 changes as applicable
- Global review to update referenced standards and technology changes



Outline

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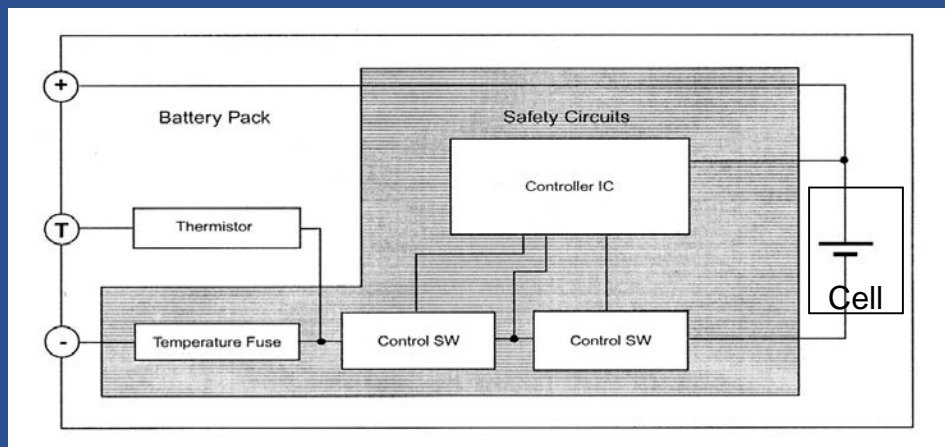
- No Product Standard (Before UL 2272) – Electric Scooters/Hoverboards
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- **Lessons Learned – System Safety**



Lithium-Ion Battery Safety

- High energy density – driven by consumer demand
- Electrode chemistries – LCO, LMO, NMC, and LFP
- Flammable electrolytes
- Requires critical safety circuits* to control voltage, current and temperature during charge and discharge

*Safety circuits do not address internal cell shorts

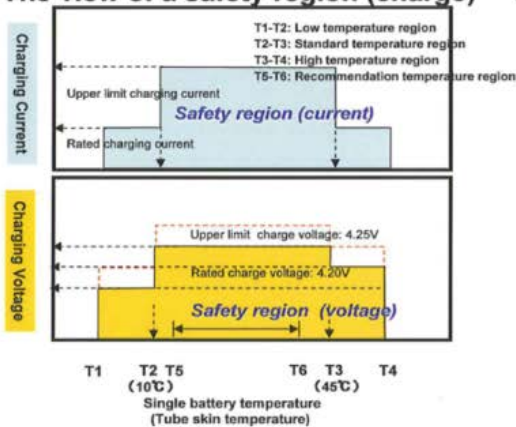


Single-cell
battery pack
with safety
circuits

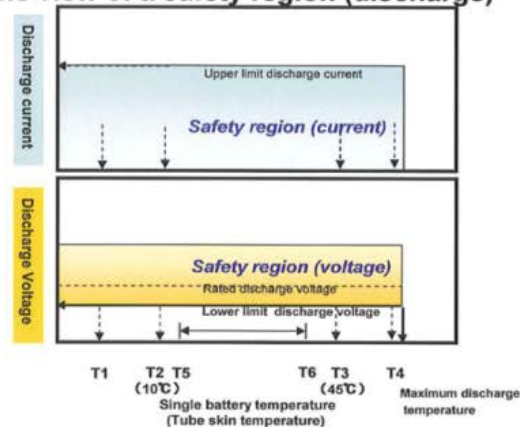


Guide to Safe Battery Use*

The view of a safety region (charge)



The view of a safety region (discharge)



Temperature domain	- T1	T1-T2	T2-T5	T5-T6	T6-T3	T3-T4	T4-
Capacity	Small	Design center value			Almost similar		
Characteristic	×	△	○	◎	○	△	×
Safety	×	○	○	○	○	○	×

- 14 -

*Japan Electronics and Information Technology Industries Association and Battery Association of Japan Source: http://home.jeita.or.jp/page_file/20110517171451_cub9MvYFEh.pdf



Manage Voltage, Current and Temperature*

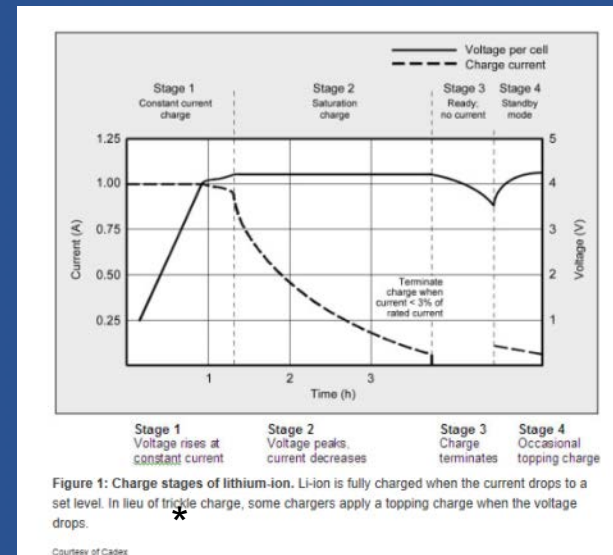
- Max charge voltage - 4.2V
- Min discharge voltage ~2.75V
- Max charge current C – capacity in A
- Max discharge current 2C or specified rate
 - 8.8A (2C) vs. 20A (5C - high discharge)
- Charge temperature - 0 to 45 °C
- Use temperature - 0 to 60 °C

*Values dependent on cell and chemistry



Manage Additional Charging Parameters

- Maintain balanced cells in multi-cell packs
- Disable charging if cell surface temperatures are $> 45\text{ }^{\circ}\text{C}$
- Disable charging or initiate pre-charge charging rate if cell is below 3 V
- Disable charging when charge current drops to .05C (no trickle charging)



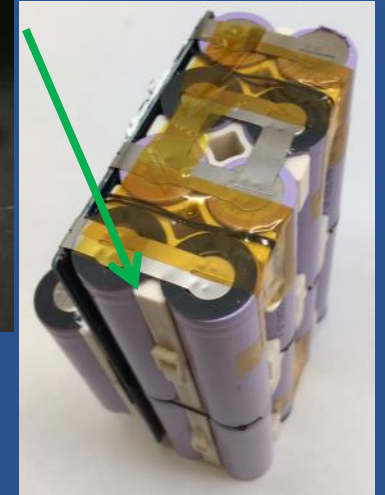
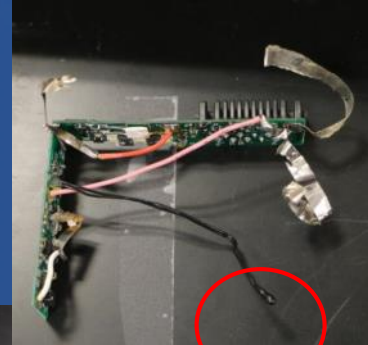
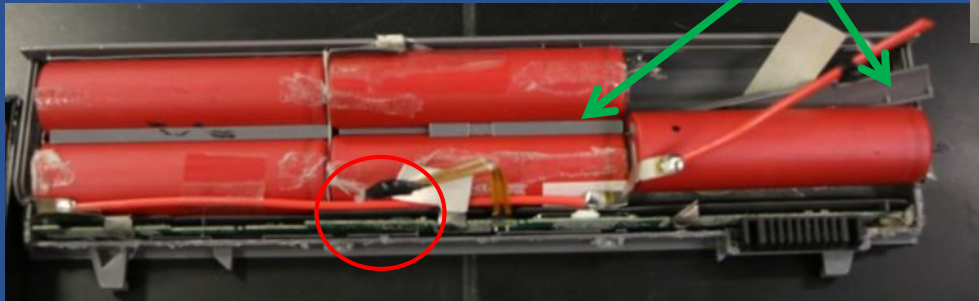
*Source:

http://batteryuniversity.com/learn/article/charging_lithium_ion_batteries



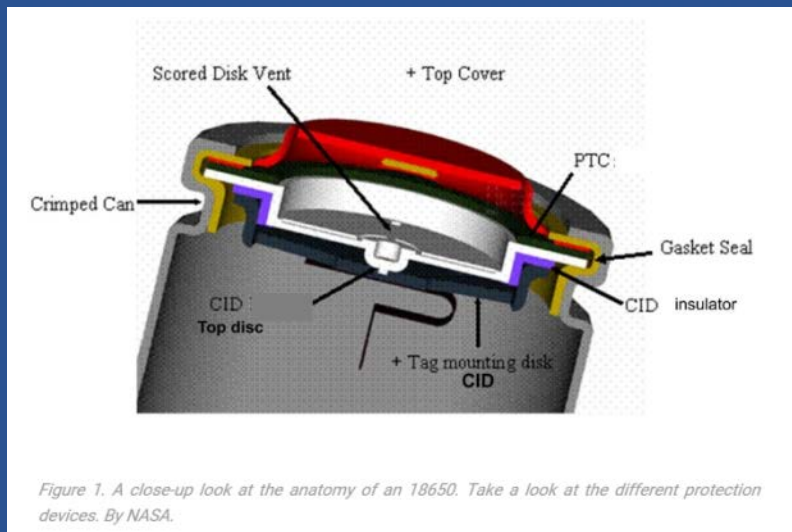
Thermal Management

- Thermal sensors
- Thermal insulators



18650 Internal Cell Safety Features

- CID – Charge Interrupting Device
- Resettable PTC – Positive Temperature Coefficient
 - Do not protect against thermal runaway due to internal faults
 - May not be applicable for high-drain applications



Source: <https://batterybro.com/blogs/18650-wholesale-battery-reviews/18306003-battery-safety-101-anatomy-ptc-vs-pcb-vs-cid>



Battery Management System (BMS) Required

- User replaceable cells need integral BMS
 - Over-charge protection
 - Charge protection
 - Over-discharge protection
 - External short-circuit protection

This board has the following features:

1. Over-charge protection
2. Charge protection
3. Over-discharge protection
4. Over-current protection
5. Short protection

This is what an 18650 battery looks like when it is connected to a PCB:



Figure 5. The anatomy of a protected 18650 battery by Lygte Info

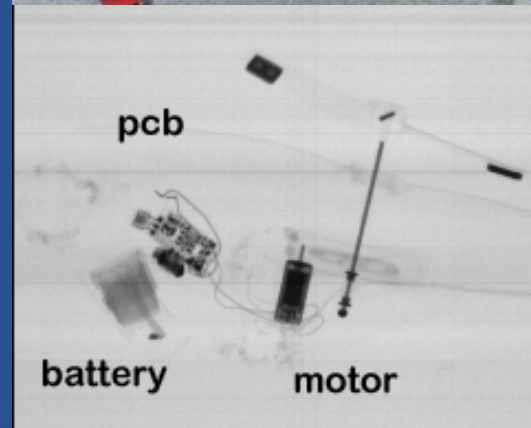
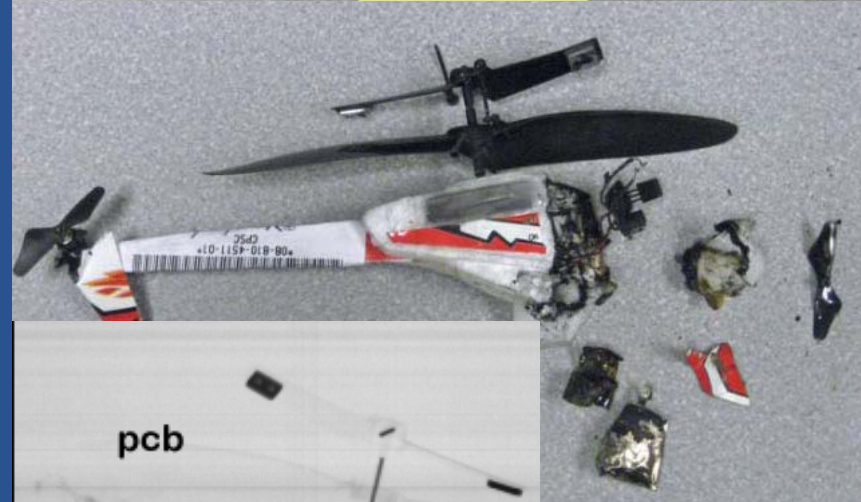
Source: <https://batterybro.com/blogs/18650-wholesale-battery-reviews/18306003-battery-safety-101-anatomy-ptc-vs-pcb-vs-cid>



Follow Best Practices – Avoid Unsafe Products

Case Study: Remote control toy helicopters provided with rechargeable lithium-ion batteries without charge/discharge control circuitry or thermal protection, allowing batteries to be overcharged or over-discharged, overheat and ignite. Posed fire hazard.

Units recalled.



CPSC Staff Recommendations for Safe Lithium-ion Battery Products

- Components and End Products should be certified to the applicable industry voluntary standard including:
 - Cells
 - Battery Pack with BMS safety circuits
 - Charger
 - End Product System
- Standards need continuous updating to ensure they address new technology and safety issues



Summary

Lithium-ion battery safety requires diligence from producer to user.

- Lithium-ion battery products should:
 - be designed and built using high quality cells
 - in accordance with applicable voluntary standards
 - suitable for the application and intended loads
 - in collaboration with cell and battery pack manufacturers
 - manufactured to best manufacturing quality control processes
 - recommended to be certified cells
 - built consistently and with proper quality and safety
 - have quality and configuration control maintained
 - have impact assessment of material or component substitutions
 - have proper warning labels to inform/educate users of the potential hazards and to closely follow manufacturer's instructions for proper use
 - have third-party certification from an accredited laboratory
 - have product safety standards that are continuously updated to address hazards identified by incident data



Questions?

