Status Report on High Energy Density Batteries Project

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1.0 Introduction

This status report summarizes FY 2017 staff accomplishments and FY 2018 preliminary plans relating to the High Energy Density Batteries Project. The FY 2018 Operating Plan designates this work to "enhance capabilities and collaborations on testing and standard development for rechargeable high energy density batteries, including lithium-ion cells, battery packs, and end-products," as a priority activity. The overall goal of the project is to improve the safety of high energy density batteries, such as those using lithium-ion based electrodes and electrolytes.

Staff has identified three key factors to address for high energy density battery safety: (1) battery management systems (BMSs) to monitor and manage charging current, discharging current, voltage, and temperature to maintain these parameters within the cell and battery pack specifications; (2) manufacturing and quality control practices to avoid defects that could result in unsafe failures; and (3) system safety to ensure the cells, battery pack, charger, and end-product function safely as a system during all modes of operation.

To address these factors for ongoing and emerging hazards from high energy density batteries, staff is focused on four main tracks: (1) improving battery and battery-powered product standards; (2) conducting outreach efforts to inform manufacturers, importers and retailers about appropriate lithium battery safety application; (3) collaborating with external partners to broaden the reach of this information campaign; and (4) working with the Office of Compliance and CBP to mitigate safety hazards by improved screening of imported products.

Although Directorate for Engineering Sciences (ES), Division of Electrical Engineering and Fire Sciences (ESEF) staff has been working to improve battery safety for several years, in 2016, two high-profile lithium battery recalls (hoverboards or self-balancing scooters and the Samsung Galaxy Note7 cellular telephone) prompted the Commission to make battery safety an agency priority. Before approving the FY 2017 Operating Plan, the Commission added an amendment to address hazards with high energy density battery products. The amendment states:

> *The Commission also has directed staff to perform additional work to address the emerging and ongoing hazards associated with high energy density batteries, including but not limited to enforcement, voluntary and mandatory standards work, import surveillance and compliance, and industry, interagency and intergovernmental cooperation. This project shall address the emerging and ongoing hazards associated with devices powered by high energy density batteries, including but not limited to lithium-ion, lithium polymer and lithium iron phosphate batteries, as well as system safety features that ensure high energy density batteries, battery packs, safety circuits, end products and chargers all work together to achieve safe operation for the intended application. This work will inform future budgets and operating plans.*

2.0 FY 2017 Accomplishments

Below is a summary of project accomplishments by track.

2.1 Improving battery and battery-powered product standards

To help identify battery and battery-powered product hazards, staff from the Epidemiology Directorate's Hazard Analysis Division conducted a search of the Consumer Product Safety Risk Management System (CPSRMS) for incidents from January 1, 2012 to July 24, 2017. The search revealed more than 25,000 incidents of overheating or fire hazards with more than 400 types of consumer products. The High Energy Density Battery Project team continues to evaluate these data to sort out potential serious hazards from minor complaints of overheating. Staff will also use the data to identify potential safety improvements to voluntary standards or other means to mitigate hazards to consumers.

End products that do not maintain the cells within their safe operating region are of primary concern. Associated fire and overheating hazards can be somewhat mitigated by compliance with relevant component and product standards and the use of safe design practices. However, some quality control and best cell-manufacturing process safety issues may not be mitigated by proper designs. Cord flexing failures, exposure to severe impacts (dropping or crushing), or environments (water, heat, and cold) can also affect cell and battery pack safety, and may be initiated or exacerbated by consumer behavior. Warning labels and outreach efforts are important in educating consumers, but are often not the most effective means to mitigate hazards. Generally, the data re-enforce staff's multipronged approach to improve battery safety by promoting best design and manufacturing practices, participating in efforts to upgrade voluntary standards requirements as necessary and educating consumers.

In executing this approach for this project, staff actively worked on voluntary standards for hoverboards/electric scooters, toys, cellular telephones, laptops, and baby monitors and continues to monitor many other lithium-ion battery product standards for power banks, household and commercial batteries (battery packs), lithium batteries (cells), light electric vehicle (EV) batteries, portable power packs, and others. Staff tested a wide range of products at the National Product Testing and Evaluation Center for Compliance testing and to help develop improved standards. With additional funds provided in the Midyear FY 2017 Operating Plan adjustment, staff procured extensive equipment to improve future testing capabilities to support battery and battery-powered product standards and Compliance evaluations. The FY 2017 specific voluntary standards accomplishments are summarized here:

- Hoverboards/Self-Balancing Electric Scooters - ANSI/CAN/UL 2272-16 *Electrical Systems for Personal E-Mobility Devices* [UL 2272] – Staff participated in the development of UL 2272, providing recommendations to the standards technical panel (STP) based on CPSC field incident data and recalls with hoverboards. The first edition of the ANSI-accredited standard was published in November 2016. Staff continues to analyze incident data and is working with the Naval Surface Warfare Center Carderock Division (NSWC CD) to test cell failure propagation in hoverboard battery packs. Staff will make recommendations to further mitigate incidents, as warranted.

  ASTM WK57360 New Specification for Standard Consumer Safety Specification for Self-Balancing Scooters (Hoverboards) – Staff participated in the development of the draft standard and provided recommendations based on CPSC field incident data on fall hazards.

Staff will continue to participate in the development of the standard and work with ASTM to publish the draft. Some of the fall hazards are related to proper battery management (*e.g.*, thermal shutdowns that may cause sudden stops), so it is important for staff to coordinate the ASTM and UL standards efforts to address both hazards.

- Battery-Operated Toys - ASTM F963-17 – Staff worked with industry and other stakeholders to draft requirements to address hazards with lithium-ion and other high-energy density cells and batteries used in toys because prior versions of the standard did not adequately address these fire hazards. In prior years, staff drafted some initial requirements and worked with industry and other stakeholders to refine these requirements into consensus requirements for ASTM F963. The requirements were balloted and accepted into the new version of ASTM F963-17 and have become part of the mandatory CPSC Toy Regulation. Staff will continue to monitor field incidents to determine if the requirements are sufficient to mitigate hazards.

- Cellular Telephones and Portable Computers - Since 2005, staff 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 the industry mitigate hazards with cellular telephones and laptops. Based on consumer demand for product features, battery energy density continues to increase and application performance enhancements stress batteries more than prior generations of products.

  Early in FY 2017, staff initiated discussions with CTIA, a trade association that represents the United States wireless communications industry and the companies throughout the mobile telephone system, to review and revise IEEE 1725-2011 and IEEE 1625-2008. These standards are the foundations for the CTIA certification of battery-powered cellular telephones and mobile computing products. The Samsung Galaxy Note7 smartphone recalls (16-266 and 17-011) suggest that these standards could benefit from a thorough review, and possibly revision, to ensure the standards are keeping up with new technologies and higher energy density batteries, charging systems and their use in these products. In April 2017, staff presented recommendations for safety improvements at a CTIA battery working group to initiate the review of these IEEE standards. Staff continued to support safety recommendations at a CTIA battery working group meeting on October 17, 2017, to plan for the revision process and the funding necessary to perform project management for the revision of the standards. Staff anticipates that the revision would take approximately 2 years for IEEE 1725, and revision of IEEE 1625 would follow. The presentation is provided as Appendix I.

- Baby Monitors - In late 2016, after completion of new ASTM F963 battery requirement revisions, staff initiated discussions with the working group chair of ASTM F2951 to add requirements for battery-powered baby monitors, based on CPSC field incident data and some battery-powered baby monitor recalls. In May 2017, these requirements were initially balloted. Staff will continue to work with the working group to address comments and complete requirements for inclusion in ASTM F2951.

2.2 Conducting outreach efforts to inform manufacturers, importers, and retailers about responsible lithium battery application

In April 2017, ESEF staff presented *Lithium-ion Battery Risk Management in Consumer Products on Battery Safety Concerns in Electronic Nicotine Delivery Systems (ENDS)* at a workshop on ENDS (or e-cigarette) battery safety that the Food and Drug Administration (FDA) sponsored. This presentation shared lithium-ion battery safety information on consumer products to manufacturers of battery-powered ENDS manufacturers. This presentation is provided as Appendix II. Additional information is provided on this presentation in section 1.3.

In May 2017, ESEF and Office of International Programs staff, in coordination with members of the International Federation of Inspection Agencies (IFIA), developed training materials for a workshop to aid manufacturers in understanding the safety standards and best design and manufacturing practices to be implemented during development and fabrication of lithium-ion battery products intended to be exported to the United States. The CPSC staff presentation, *Lithium-Ion Battery Safety Standards for Consumer Product Import into the United States*, was given in Shenzhen, China, in May 2017. The presentation provided information on CPSC's risk management approach, battery incident data and recalls, case studies of product failures, including examples in which no applicable standards were available, as well as instances where standards were well-established, and provided lessons learned and best practices from a system safety approach. CPSC staff and IFIA member testing laboratories' presentations provided manufacturers with recommendations to mitigate safety risks and ease importation of products into the United States. The presentation is provided in Appendix III.

As part of the manufacturer's training trip to China, ESEF staff also visited several cell and electronics manufacturers in China, Korea, and Japan. The goals of these meetings were to discuss and to gain knowledge of the challenges that all levels of manufacturers (small to large) face. Additional information is provided on this presentation in section 1.3.

In September 2017, CPSC staff participated in a workshop on global codes and standards for lithium-ion battery products at the 2017 North America Battery Show. This pre-workshop session was in coordination with a CSA standards representative and with the American Airlines Dangerous Goods Manager, who expressed appreciation that CPSC is working to address these product safety issues. The airline industry has documented a number of battery products smoking and catching fire in both carry-on and checked luggage. Staff presented a tailored version of the Shenzhen, China manufacturer's training workshop. This presentation is provided in Appendix IV.

Throughout the year, staff also supported the Small Business Ombudsman (SBO) on battery-related issues and questions (toys and fidget spinners) that the SBO received from manufacturers.

2.3 Collaborating with external partners and stakeholders

In FY 2017, staff collaborated with many external partners and stakeholders to leverage as many resources as possible to reduce the likelihood of battery-related fires, in addition to the preceding:

- The National Transportation Safety Board (NTSB) and UL formed the Battery Safety Council (BSC) after the investigation of some lithium battery failures on new Boeing

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. The goals of the BSC are to collaborate across industries to share battery safety-related topics to share ideas and recommended practices for safe design, manufacture, test, handling, storage, use, transportation, and recycling of batteries. Staff participated in BSC meetings in January and June 2017, where staff discussed the agency's High Energy Density Battery project to mitigate fire risks and CPSC staff work on mitigating single-cell fault propagation within multi-cell batteries.

- The Lithium Battery Inter-Agency Coordination Group (LBIACG) was formed in fall 2016, in the aftermath of the Samsung Note7 recall, to improve cross-agency communications on battery safety issues. The LBIACG is co-chaired by staff 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 numerous agencies that have the following interests:
    - Administrative, regulatory or law enforcement purview over lithium batteries
    - Commitment to partnerships that indicate an ability to consider a broad public policy perspective and openness to support solutions that serve the broader safety interest
    - A willingness to participate in joint safety and/or enforcement efforts.

  Staff participated in meetings in January, April, and July 2017, where staff discussed the agency's High-Energy Density Battery project to mitigate fire risks. To facilitate detailed discussions in specific subject areas, the LBIACG established three subcommittees: International, Research and Recalls. CPSC staff participates on the Research and Recalls working groups.

- ESEF staff established a working relationship with the FDA staff, who was leading their agency's efforts on e-cigarettes, to share CPSC staff's knowledge on lithium-ion battery safety and coordinate actions on areas of mutual interest. Staff connected FDA engineers with the BSC, LBIACG, and the Department of Defense to share information and to gain safety knowledge from other industries. Staff established an information-sharing agreement with FDA under section 29f, to provide incident information to FDA to support their efforts in this area. This collaboration helped both agencies address concerns of members of the Senate Commerce Committee, and improved the government's ability to share information and develop the best approach to battery safety across jurisdictions. As previously indicated, ESEF staff also presented and participated in a panel discussion at the FDA Workshop in April 2017.

- Staff continues to collaborate with the Portable Rechargeable Battery Association (PRBA) and its members to consider ideas to mitigate overheating and fire risk associated with lithium-ion battery products. The PRBA is an independent, nonprofit public service organization dealing with recycling and safety transportation issues.

- Staff continues to collaborate with many stakeholders through participation in National Electrical Manufacturers Association (NEMA), UL, IEEE, and ASTM standards development processes to improve consumer safety from high-energy density batteries and consumer products using these batteries. Some of these standards are listed above and in the agency's voluntary standards activity report for 2017.

- As part of the manufacturer training trip to China in May 2017, ESEF staff participated in a training seminar in Shenzhen, and targeted design manufacturers and end user specialists of consumer products that use high performance batteries. CPSC conducted the training in cooperation with the China Council for the Promotion of International Trade (CCPIT), Underwriters Laboratories, and International Federation of Inspection Agencies. The purpose of the seminar was to address the emerging and ongoing hazards associated with devices powered by high energy density batteries, including but not limited to lithium-ion, lithium polymer, and lithium iron phosphate batteries, as well as system safety features that ensure high energy density batteries, battery packs, safety circuits, end products, and chargers all work together to achieve safe operation for the intended application. Approximately 125 company representatives attended. Results from participants' evaluations and feedback from industry speakers, CCPIT, and UL demonstrated the event was worthwhile and also indicated a high degree of satisfaction overall with the content of the presentations and the format.

- ESEF staff also held meetings with cell and electronics manufacturers and government agencies in China, Korea, and Japan. The goals of these meetings were to discuss and to gain knowledge of the challenges that all levels of manufacturers (small to large) confront and to see what safety issues other governments are experiencing. The government meetings confirmed that there are similar incidents and concerns in China, Korea, and Japan, and these countries are also focused on lithium-ion battery safety. China and Korea are updating their standards and regulations, and revisions are expected in late 2017, or early 2018. Meetings with manufacturers indicate that manufacturers are working diligently to address manufacturing processes that can lead to cell overheating issues. Smaller manufacturers may find it difficult to afford expensive process control systems for safety. High-volume production involves very complex manufacturing systems and maintenance tracking systems. These costly processes are necessitated by the scale of manufacturing and supported economically by the volume of production.

- With additional funding provided by FY 2017 mid-year funds, ESEF was able to extend the CPSC/NSWC CD Inter-Agency Agreement (IAA) to provide single-cell thermal propagation testing, a review of new safety technologies and research being performed by government laboratories and industry, and to provide additional support for LBIACG work that government agencies may consider. This agreement also provides a means for staff to collaborate and share safety information with the Navy's electrochemical and safety experts as Compliance activities arise.

2.4 Working with the Office of Compliance and U.S. Customs and Border Protection (CBP) to mitigate safety hazards by improved screening of imported products

In support of Compliance investigations and their work with CBP to mitigate the safety hazards associated with lithium-ion battery products, EXHR staff have tested and completed over 135 technical product safety assessments (PSAs) since December 2015 when hoverboard incidents began to increase. The PSAs include these product categories: personal e-mobility devices including hoverboards (71), battery chargers (20), lighting products (13), audio-video equipment (12), computer equipment (12), and toys (6). This work supported 43 recalls since December 2015 involving over three million lithium-ion battery products. During this time, the most number of recalls and products recalled was from: e-mobility devices (21 recalls, 522,000 products), laptops (7 recalls, 184,000 products), and cellular phones (3 recalls, 1,930,000 products).

3.0 Ongoing staff efforts to mitigate hazards with lithium-ion batteries in consumer products

Building on the accomplishments of staff in FY 2017, staff plans to continue to be actively engaged on all relevant voluntary standards, as well as outreach efforts and collaborations to help mitigate high energy density battery-related fire incidents. Specific plans include:

- Staff will continue to actively participate in developing new or improved voluntary safety standards for all consumer products powered by lithium-ion batteries, using data to drive the priorities.

  This work will include working with standards developers, where appropriate, to harmonize existing standards to simplify and reduce testing burdens. Currently, there are several standards for lithium-based batteries, including two ANSI-accredited standards. Staff plans to engage with standards developing organizations to address the need for end-product standards to include requirements that lithium-ion cells are within their operating specifications throughout the use of the end-product. Additionally, staff plans to work with stakeholders as standards are developed to address safety risks from new technologies and observed field incidents, including:

  - IEEE 1725 – Staff will work with industry and other stakeholders to update the standard to address new technologies and lessons learned from recent related recalls.
  - IEEE 1625 – Staff will work with industry and other stakeholders on the next update to the standard, taking into account the IEEE 1725 requirements and lessons learned from single-cell products to multi-cell and computing products.
  - Various UL standards:
    - Staff will work with industry and other stakeholders to improve marking and labeling cells.

        - Staff will work with industry and other stakeholders on considerations for design Failure Modes and Effects (FMEA) analysis, based on CPSC field data.
        - Staff will work with industry and other stakeholders to consider minimum factory inspection standards and using certain best practices for cell manufacturing processes.

- Outreach efforts:
    - Staff will update CPSC battery safety information on CPSC's website for consumers and industry.
    - Staff will continue information and education activities, including presentations of CPSC staff findings to educate stakeholders on possible consequences of not following standards for end products or best cell manufacturing processes.

- Staff plans to collaborate with presentations and training, including American Council on Electrical Safety and Battery Safety 2018.

- Staff will continue to work with DOT, PHMSA, FAA, and other government agencies, leveraging their knowledge, regulations, and proposed tracking systems to help identify and track consumer product risks.

Appendix I: Staff April 11-12 2017 Presentation at CTIA meetings on IEEE 1725

CPSC Lithium-ion Battery Project Overview and Staff Recommendations for Revising IEEE Voluntary Standards

Douglas Lee

CTIA/IEEE Meeting

Mountain View, CA

April 11, 2017

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

Agenda

- CPSC 2017 Battery Project Overview
- Improvements to IEEE 1725 and IEEE 1625

Battery Project Scope

- CPSC staff directed by Commission 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 inform future budgets

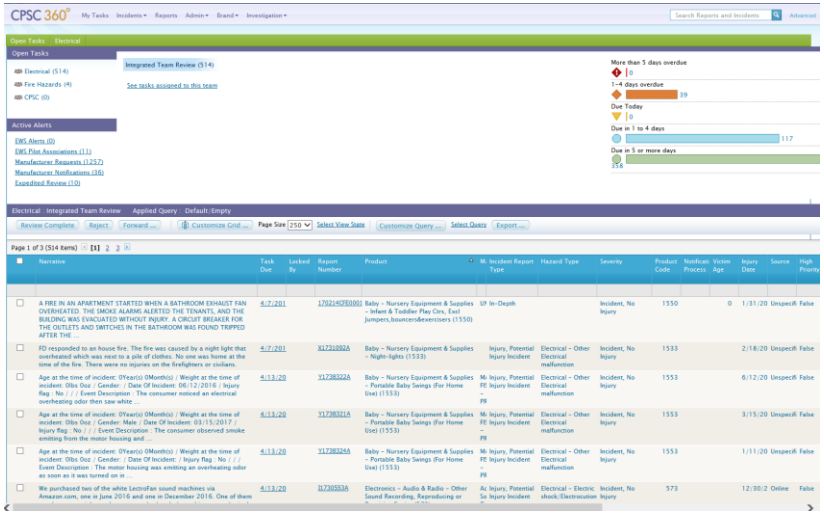
CPSC Lithium-ion Battery Project

- Assess reported incidents and injury cases
- Review adequacy of voluntary and mandatory standards
- Expand import surveillance and compliance
- Enhance industry, interagency, and intergovernmental cooperation on battery safety issues

Consumer Product Safety Risk Management System (CPSRMS)

- Anecdotal Incident reports from public sources
- Search of Incident reports from 1/1/12 to 1/24/17
  Narrative field search terms:

  LI-ION/LITHIUM/POLYMER/BATTER/CHARG
- CPSRMS – 21,687 incident reports from 483 product codes



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
- 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

Additional CPSC Data

- National Electronic Injury Surveillance System (NEISS)
- Death Certificates
- CPSC In-Depth Investigations (IDIs)

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 (FY2004-2007)

Comparing recalls from FY 2004-2007 – Previous Peak

- FY2004: 5 recalls – 250,500 units (33 incidents)
- FY2005: 10 recalls – 1,317,075 units (82 incidents)
- FY2006: 12 recalls – 4,579,300 units (110 incidents)
- FY2007: (Oct 2006 – Jan 2007):
  4 recalls – 345,800 units (9 incidents)

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)

Industry, Interagency, Intergovernmental Cooperation

- Domestic
  - ANSI, UL, ASTM, and IEEE Battery Standards Committees, CTIA, PRBA, Technology Developers, U.S. Navy, Battery Safety Council, Battery Safety Conferences, Industry Experts, Federal Interagency Working Group
- International
  - Australia, Japan (METI, NITE, BAJ), Mexico, Canada, Vietnam (STAMEQ), China (AQSIQ, CBA), Korea (KATS, KCA)
  - Manufacturer training in China w/ UL May 2017

Relevant Voluntary Standards Activity

- Hoverboards/Electric Scooters - Outline of Investigation (1/16), New 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*

CPSC Staff Objectives for CTIA/IEEE

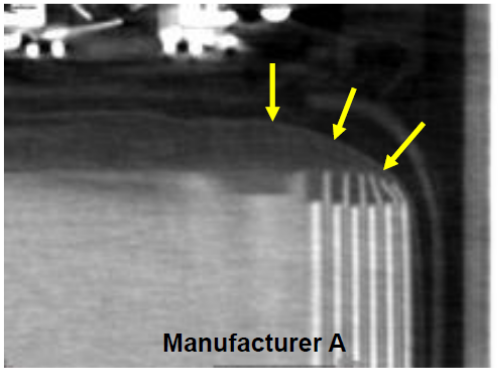
- Mitigate risks from consumer use of cellular phones and mobile computing devices
- Are standards keeping up with technology?
- Would additional or independent testing have uncovered reported issues?

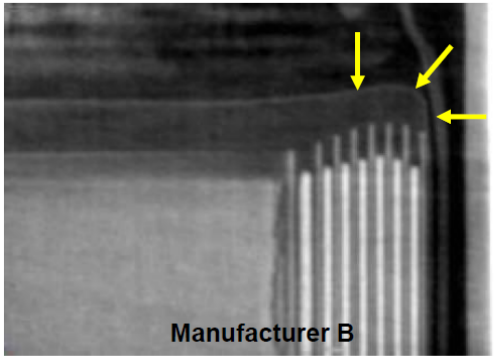
Manufacturing Design Issue A*

Exponent®
Engineering and Scientific Consulting 4

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





* Source: https://news.samsung.com/global/samsung-electronics-announces-cause-of-galaxy-note7-incidents-in-press-conference (Exponent slides)

IEEE 1725 Requirements Review and Staff Recommendations

- 5.4 Cell core assembly
  - (new) Corner clearance validation process
- 5.4.1.3 Detection of damaged cores
- 5.5.6 Cell Aging
- 5.5.7.1 Testing procedures
- 5.6.6.2 Dissection of cycled cells
  - (new) verify 4 corner radius (prismatic)
  - (new) verify top and bottom of core (cylindrical)

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

*Source: https://news.samsung.com/global/samsung-electronics-announces-cause-of-galaxy-note7-incidents-in-press-conference (Exponent slides)

IEEE 1725 Requirements Review and Staff Recommendations

- 5.5.6 Cell Aging
- 5.5.7.1 Testing procedures
- 5.6.6.2 Dissection of cycled cells
  - (new) verify electrode tab welds
  - (new) verify insulation tape at tabs in key areas
  - (new) verify insulation tape at electrode ends
  - (new) verify insulation tape at radius

IEEE 1725 Requirements Review and Staff Recommendations

- 9.2 User Interactions and Responsibilities (information to user)
  - (new) Remove from front and back pants pocket when sitting
  - (new) Cases are recommended to protect the phone from physical damage
- (new) 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

Third-Party Certification

- Independency of Certification Program
- Certification
  - Self
  - Third-party
  - Third-party verification
- Consider reviewing process to ensure it is equivalent to third-party certification process

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Appendix II: CPSC Presentation at FDA ENDS Battery Workshop

Lithium-ion Battery Risk Mitigation in Consumer Products

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FDA Workshop on Battery Safety Concerns in Electronic Nicotine Delivery Systems

White Oak, MD

April 19-20, 2017

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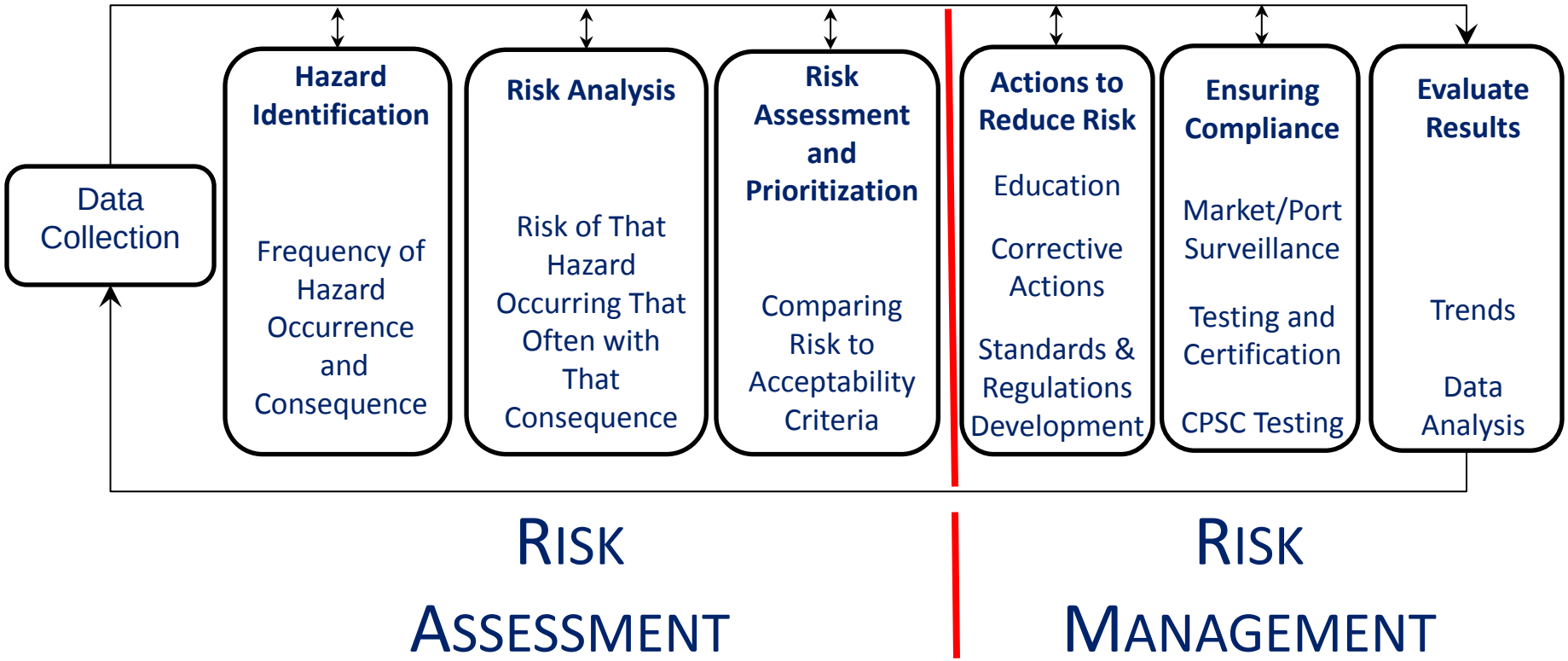
Outline

- CPSC Risk Management Process
- CPSC Project on Lithium-ion Batteries
- Battery Product and E-Cigarette Incident Data
- Lithium-ion Battery Safety Features
- Recent Consumer Product Safety Issues

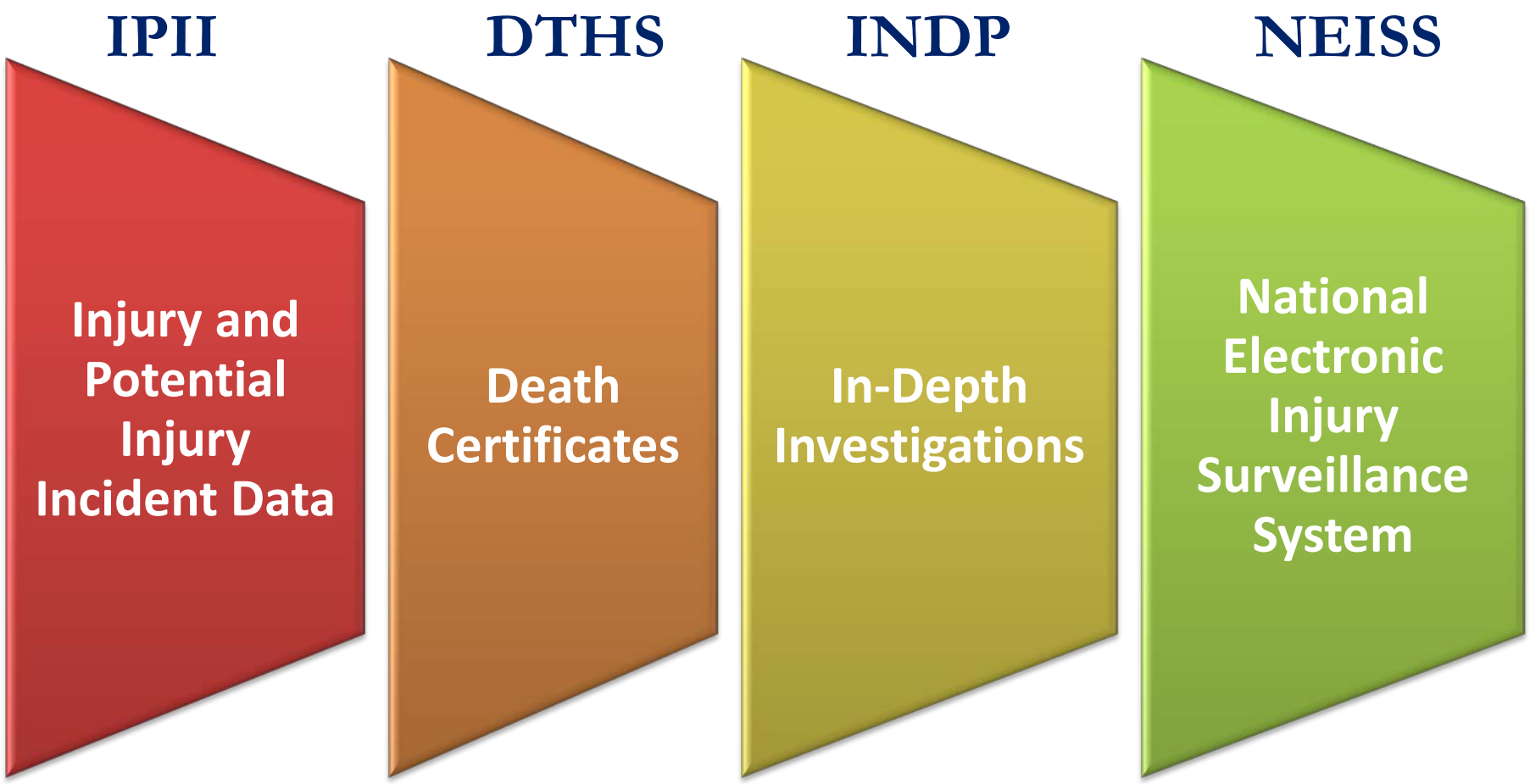
Outline

- CPSC Risk Management Process
- CPSC Project on Lithium-ion Batteries
- Battery Product and E-Cigarette Incident Data
- Lithium-ion Battery Safety Features
- Recent Consumer Product Safety Issues

CPSC Risk Management Process



Data Collection Systems



Actions to Reduce Risk

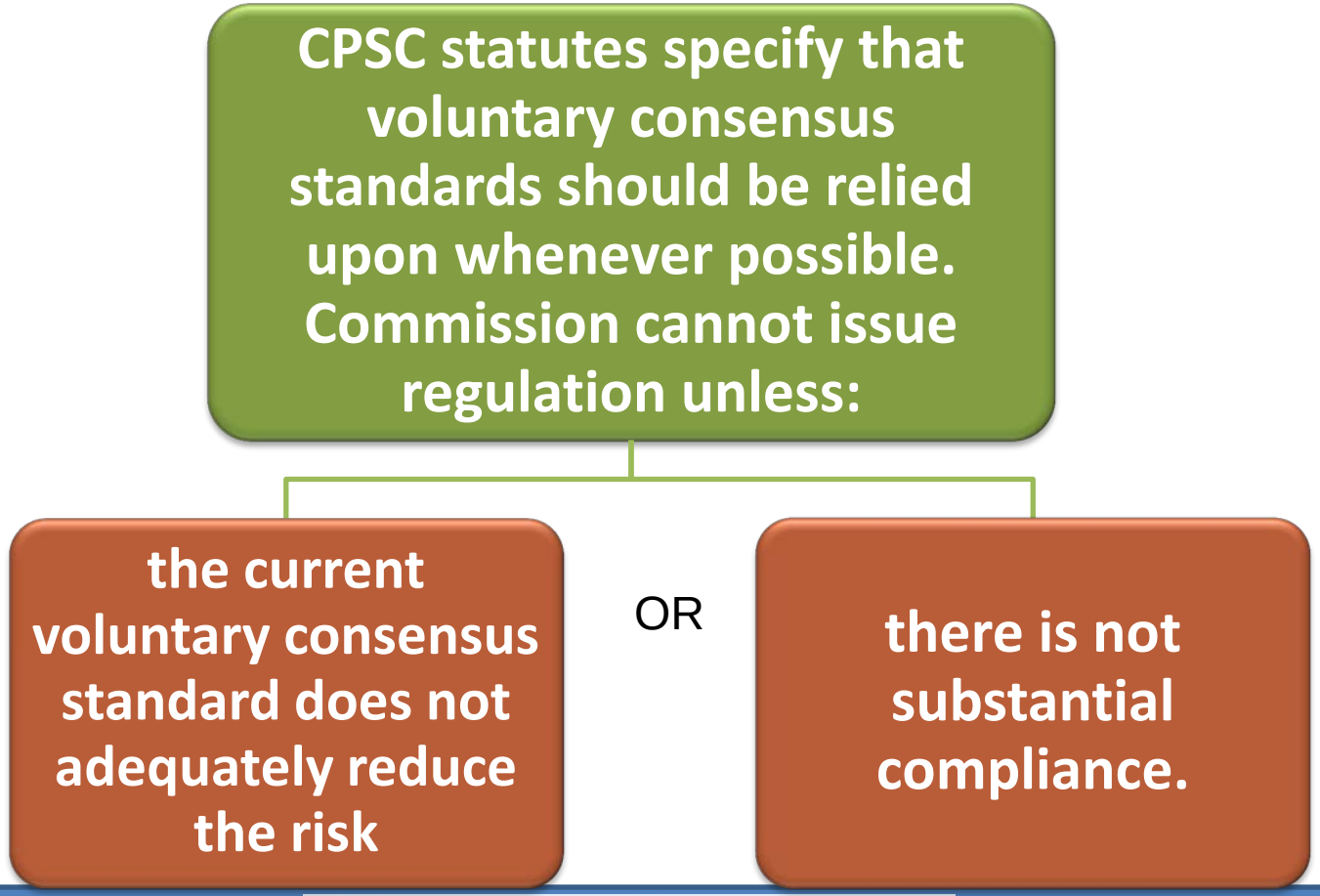
Strategy: Reduce/maintain risk at acceptable levels.

Actions to reduce risk to acceptable levels:

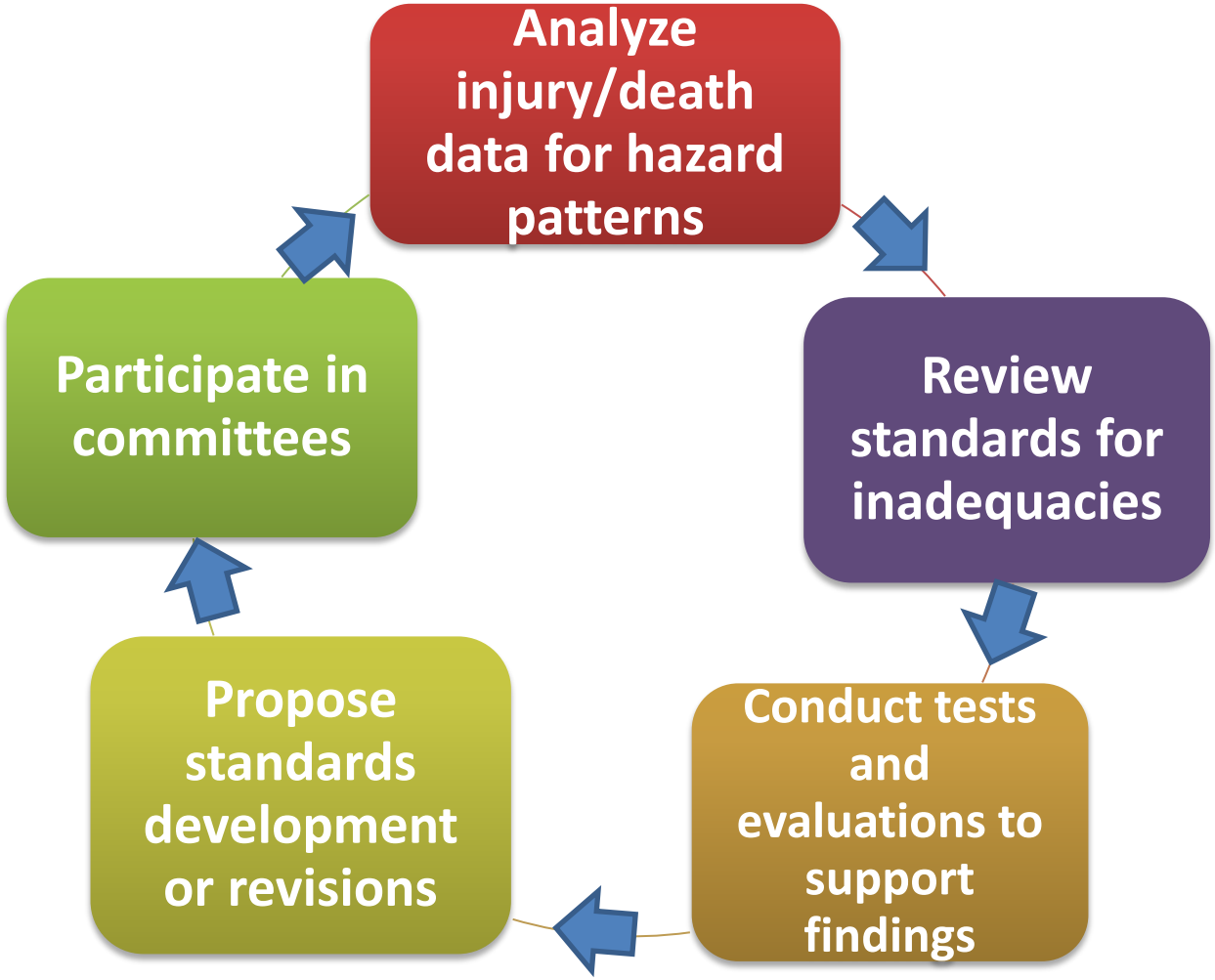
- Change or create voluntary consensus standards
- Change or create regulations
- Reach out to manufacturers, distributors, and importers
- Educate the public

REGULATIONS

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



Voluntary Standards – Staff Participation



Outline

- CPSC Risk Management Process
- CPSC Project on Lithium-ion Batteries
- Battery Product and E-Cigarette Incident Data
- Lithium-ion Battery Safety Features
- Recent Consumer Product Safety Issues

CPSC Battery Project Scope

- CPSC staff directed by Commission 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 inform future budgets

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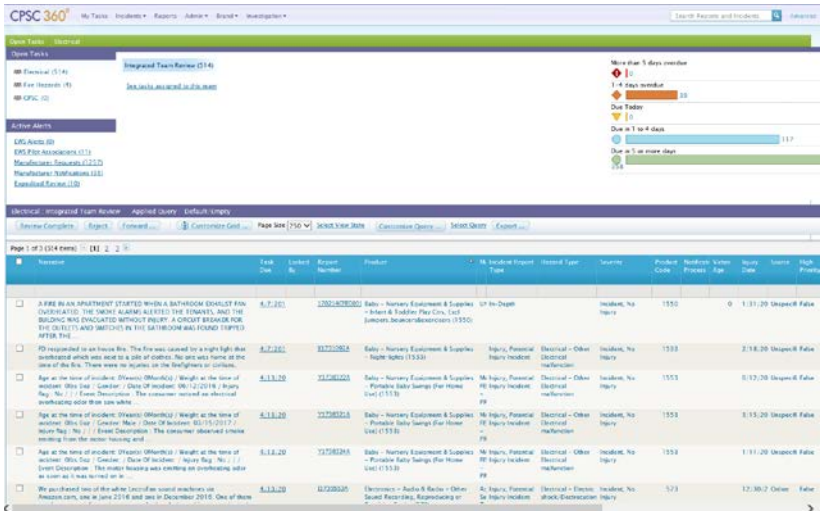
Consumer Product Safety Risk Management System (CPSRMS)

- Anecdotal Incident reports from public sources
- Search of Incident reports from 1/1/12 to 1/24/17
  Narrative field search terms:

  LI-ION/LITHIUM/POLYMER/BATTER/CHARG
- CPSRMS – 21,687 incident reports from 483 product codes



CPSRMS Data

- Manually filter incidents categorizing
  - like products
  - battery capacity/size
- 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

Additional CPSC Data

- National Electronic Injury Surveillance System (NEISS)
- Death Certificates
- CPSC In-Depth Investigations IDIs

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
  - 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)

CPSC E-Cigarette NEISS Data

- Estimated children under 5 seen in emergency departments for ingestion of liquid nicotine or e-cigarette fluids
  - 1,200 from 2010-2014
  - 1,500 in 2015

CPSC E-Cigarette Fire and Explosion Data

- 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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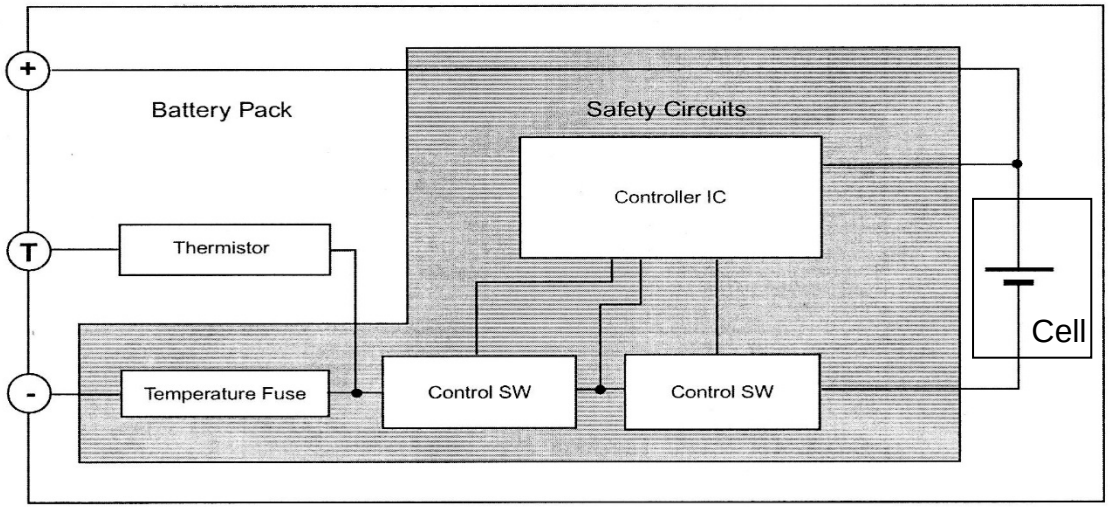
Lithium Ion Battery Safety

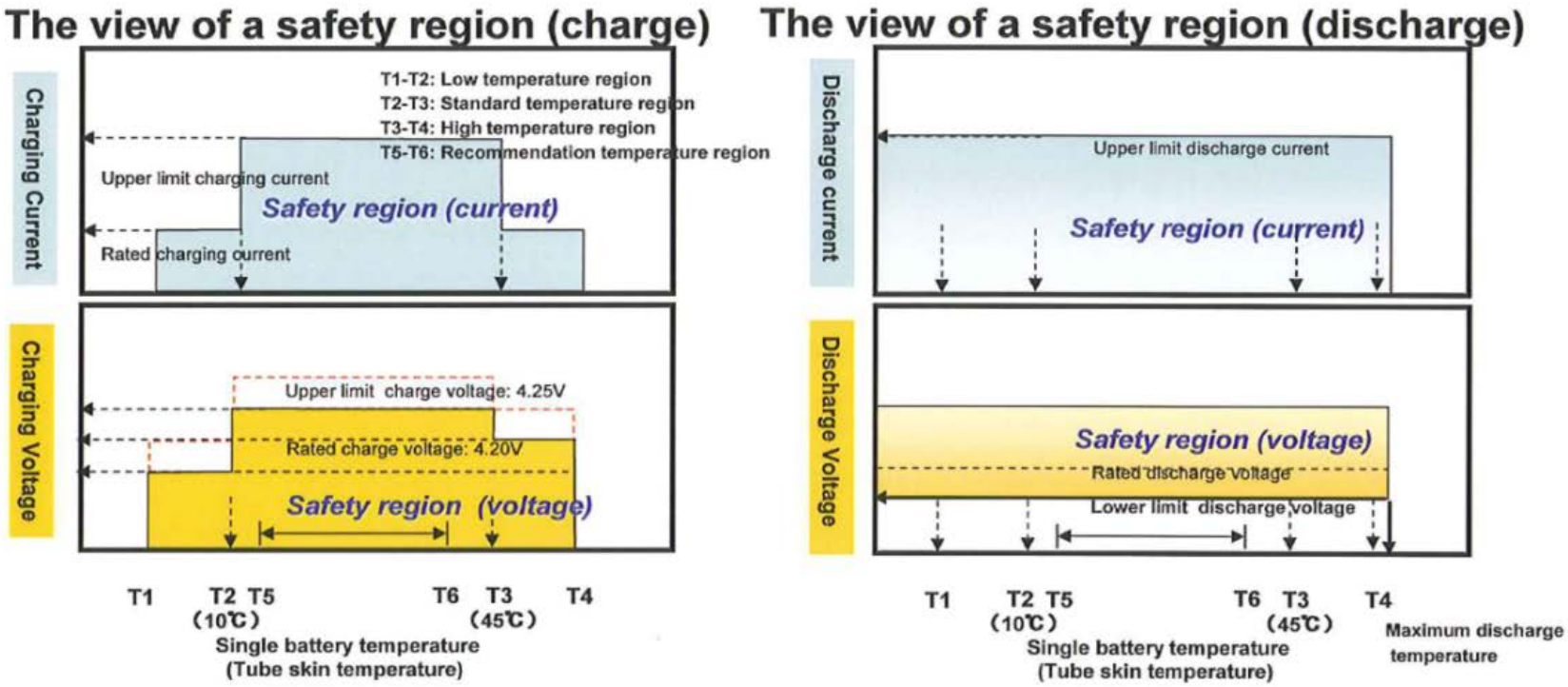
- High energy density – driven by consumer demand
- Electrode chemistries – LCO, LMO, NMC, and LFP
- Flammable electrolytes
- Requires critical safety circuits* to control voltage, current and temperature during charge and discharge

*Safety circuits do not address internal cell shorts

Single cell battery pack
With safety circuits



Guide to Safe Battery Use*



*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 (C) vs. 20A (2C - high discharge)
  - 10A to 30A (Vaping)
- Charge temperature - 0 to 45 °C
- Use temperature - 0 to 60 °C

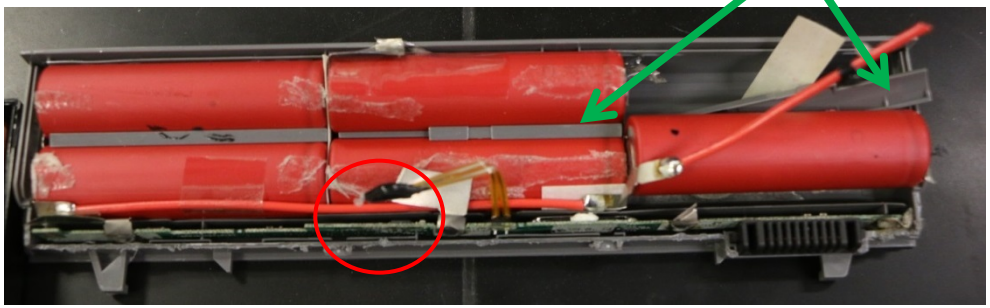
*Values dependent on cell and chemistry

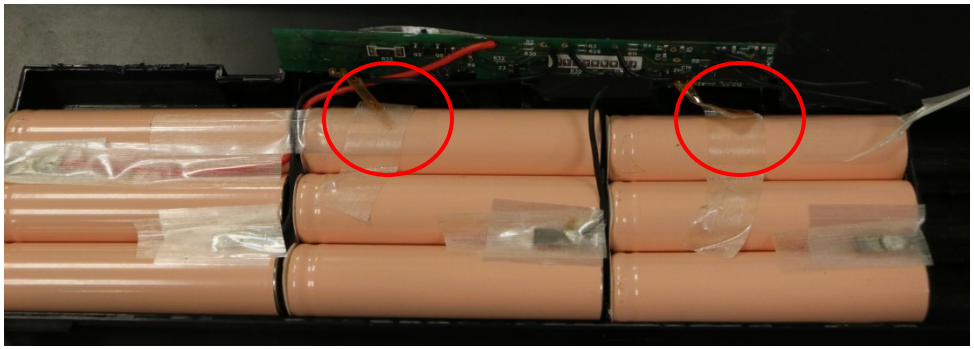
Manage Additional Charging Parameters

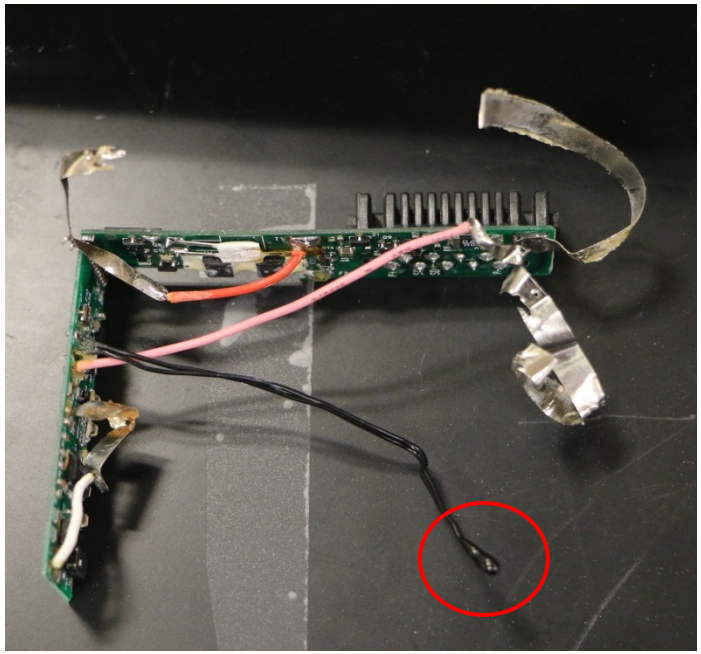
- Maintain balanced cells in multi-cell packs
- Disable charging if cell surface temperatures are > 45 °C
- Disable charging or initiate pre-charge charging rate if cell is below 3 V
- Disable charging when charge current drops to .05C (no trickle charging)

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

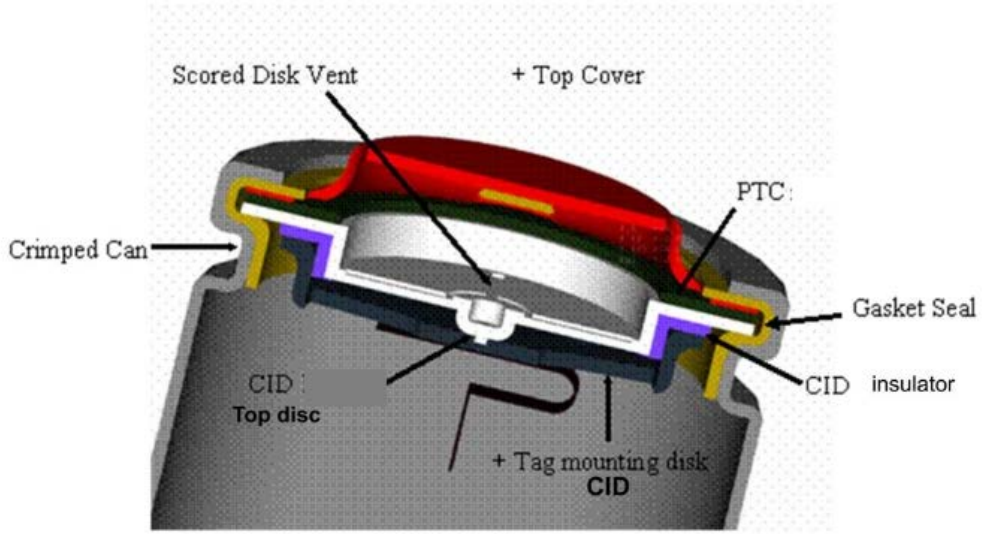


Figure 1. A close-up look at the anatomy of an 18650. Take a look at the different protection devices. By NASA.

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

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

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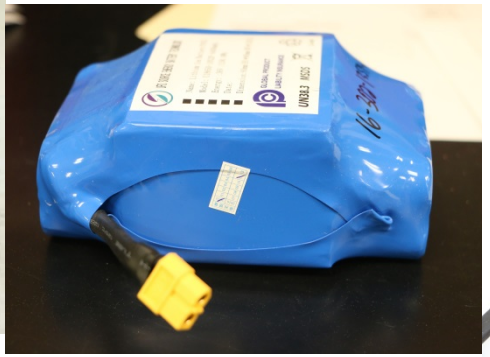
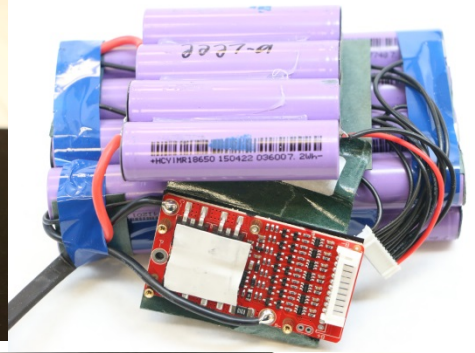
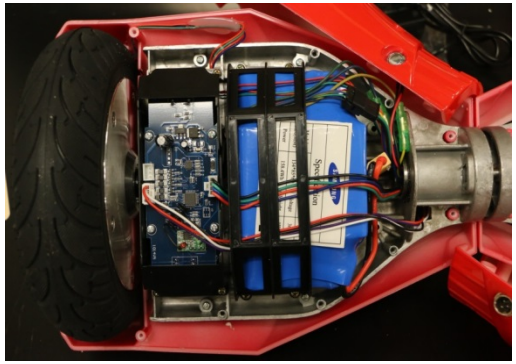
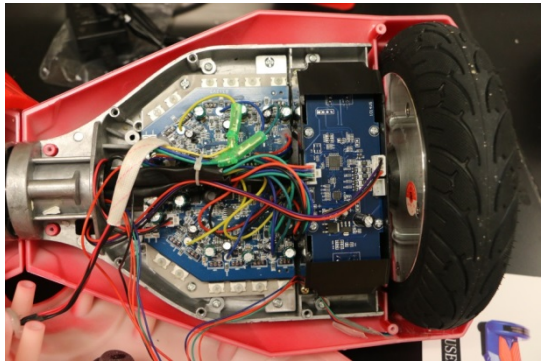
- Recent Consumer Product Safety Issues
  - A look at hoverboards

Self-Balancing Electric Scooters or Hoverboards









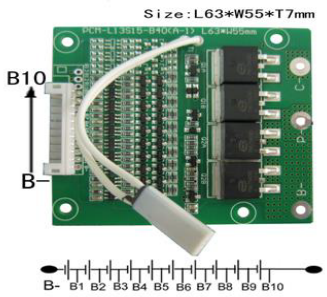
Incidents from Self-Balancing Electric Scooters or Hoverboards

Incidents from Self-Balancing Electric Scooters or Hoverboards

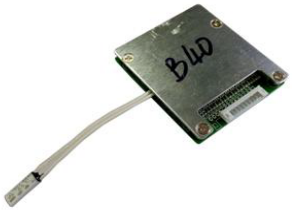
- Over 100 fires, causing more than $3M in damages
  - During and after riding
  - During and after charging
- 3 Deaths –1 fire (2 victims), 1 fall
  (MVA death excluded)
- Estimated over 10,000 Emergency Room Visits
  - ~90% from falls, *e.g.,* sudden stops and starts
  - ~15% head injuries
  - ~50% arm injuries
  - ~40% fractures
  - ~30% sprain/abrasions

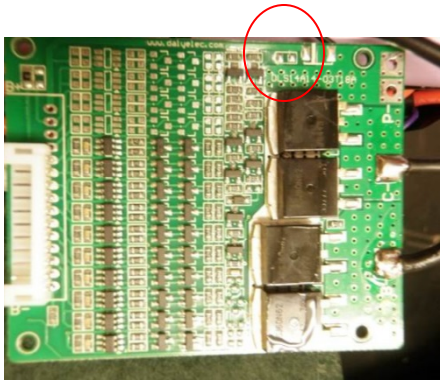
Temperature Management Sensor Not Used

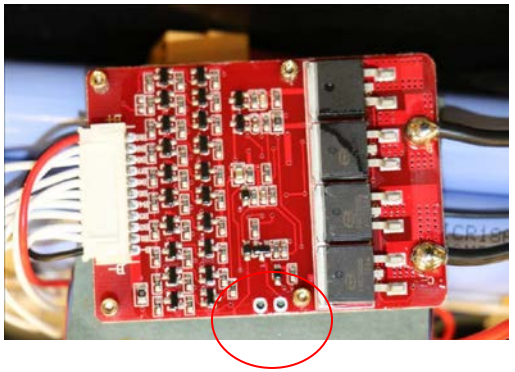
Protection Circuit Module Specifications For 37V Li-ion/Li-PO Battery Pack			
Model: PCM-LI37V15A			
No.	Test item		Criterion
1	Voltage	Charging voltage	DC：42V CC/CV（4.2V/1Cell）
		Balance voltage for single cell	
2	Current	Balance current for single cell	
		Current consumption for single cell	≤20μA
		Maximal continuous charging current	15A
		Maximal continuous discharging current	15A
3	Over charge Protection	Over charge detection voltage	4.25±0.05V
		Over charge detection delay time	0.5S—2S
		Over charge release voltage	4.05±0.1V
4	Over discharge protection	Over discharge detection voltage	2.50±0.1V
		Over discharge detection delay time	10—200mS
		Over discharge release voltage	3.0±0.1V
5	Over current protection	Over current detection voltage	0.2 ± 0.015 V
		Over current detection current	100±10A
		Detection delay time	5ms—60ms
		Release condition	Cut load
6	Short protection	Detection condition	Exterior short circuit
		Detection delay time	200-800us
		Release condition	Cut load
7	Resistance	Protection circuitry（B- TO P-）	≤30mΩ
8	Temperature	Operating Temperature Range	-40～+85℃
		Storage Temperature Range	-40～+125℃
		Discharging Temperature protection	65±5℃

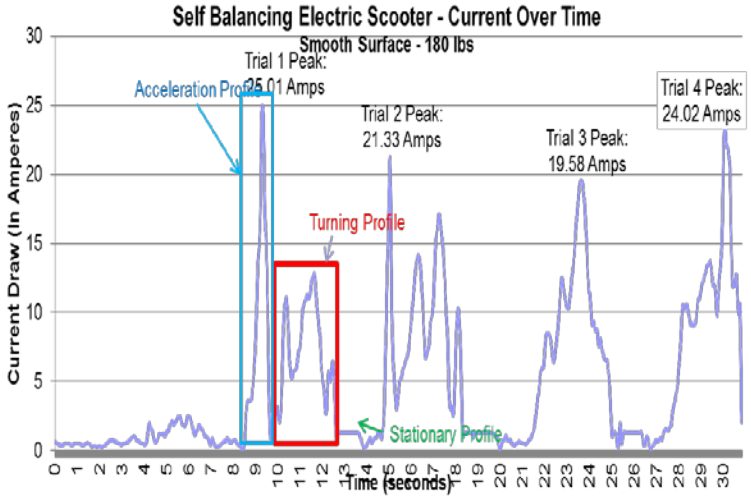


B + / P + =Charge +/ Discharge +
C - =Charge - / Discharge -
P - =NC



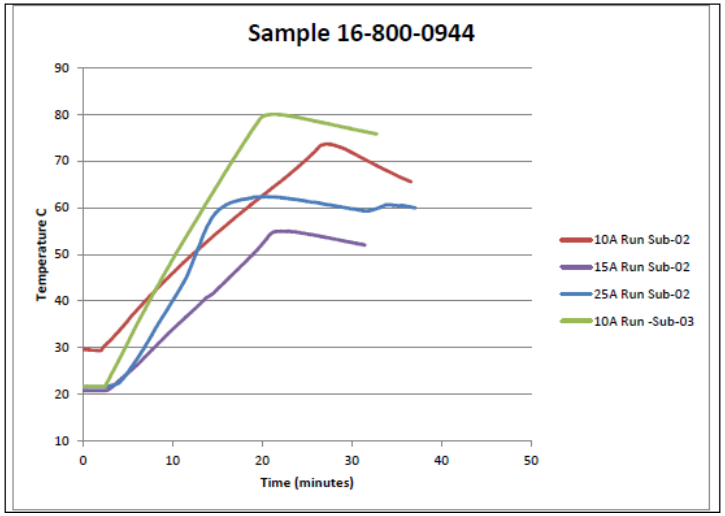






Staff Hoverboard Assessment

- 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 leading to catastrophic failure of the entire battery pack
- Over 500,000 units recalled



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

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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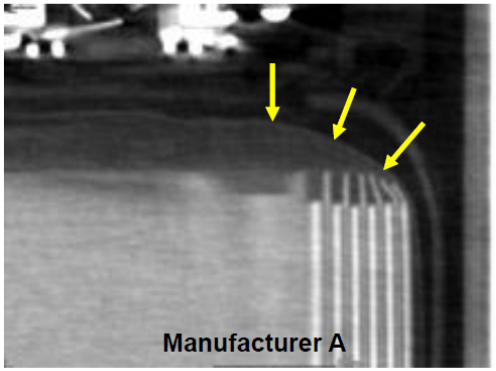
  - A look at Samsung Note 7 cellular phones

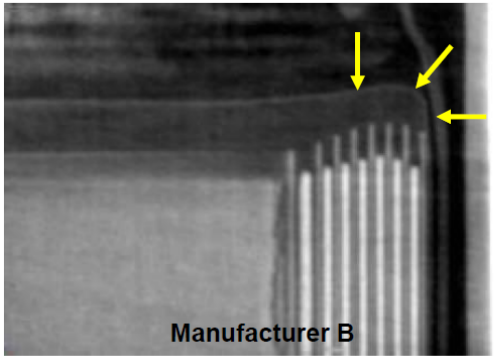
Manufacturing Design Issue A*

Exponent®
Engineering and Scientific Consulting 4

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





* Source: https://news.samsung.com/global/samsung-electronics-announces-cause-of-galaxy-note7-incidents-in-press-conference (Exponent slides)

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)
  - verify top and bottom of core (cylindrical)

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

*Source: https://news.samsung.com/global/samsung-electronics-announces-cause-of-galaxy-note7-incidents-in-press-conference (Exponent slides)

IEEE 1725 Requirements Review and Staff Recommendations

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

IEEE 1725 Requirements Review and Staff Recommendations

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

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

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Appendix III: China Battery Training – May 2017

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

<u>15(j) Rule</u>

- 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

Injury and Potential Injury Incident

Medical Examiners and Coroners Alert Program (MECAP)	News Clips	Hotline Calls	Internet Reports	Compliance Reports	Federal and State Agency Referrals	Other Reports

Death Certificates Database (DTHS)

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

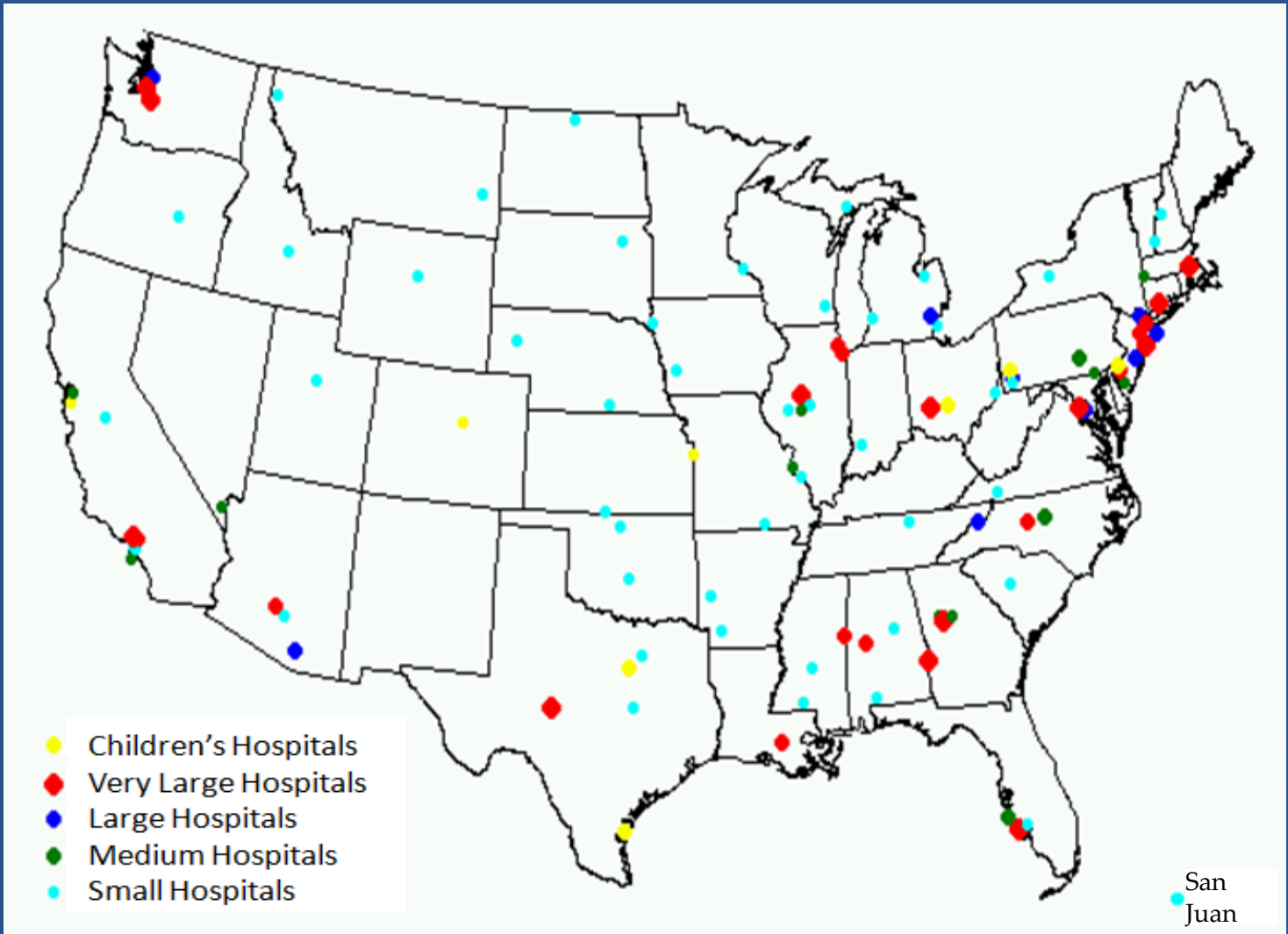
In Depth Investigations Database (INDP)

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

National Electronic Injury Surveillance System (NEISS)

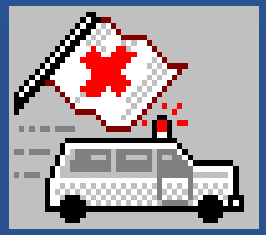
- National sample
  - Data collected from approximately 100 hospital emergency rooms around the country
  - Data weighted to provide consumer injury estimates nationwide
- Multilevel system
  - About 395,000 consumer product-related injury reports annually
  - About 300,000 other incident reports annually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

Map of NEISS Hospital Locations

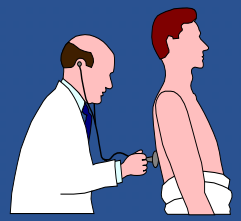


Why Emergency Department Data?

- Large numbers of injuries are treated.



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



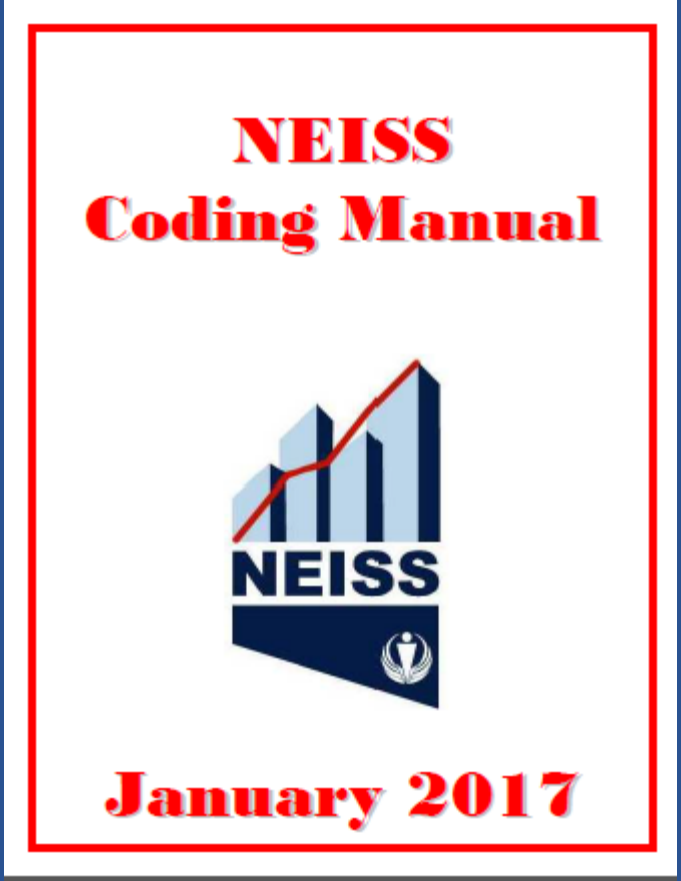
- Hospitals have been very cooperative in supporting CPSC data collection activities.

- 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

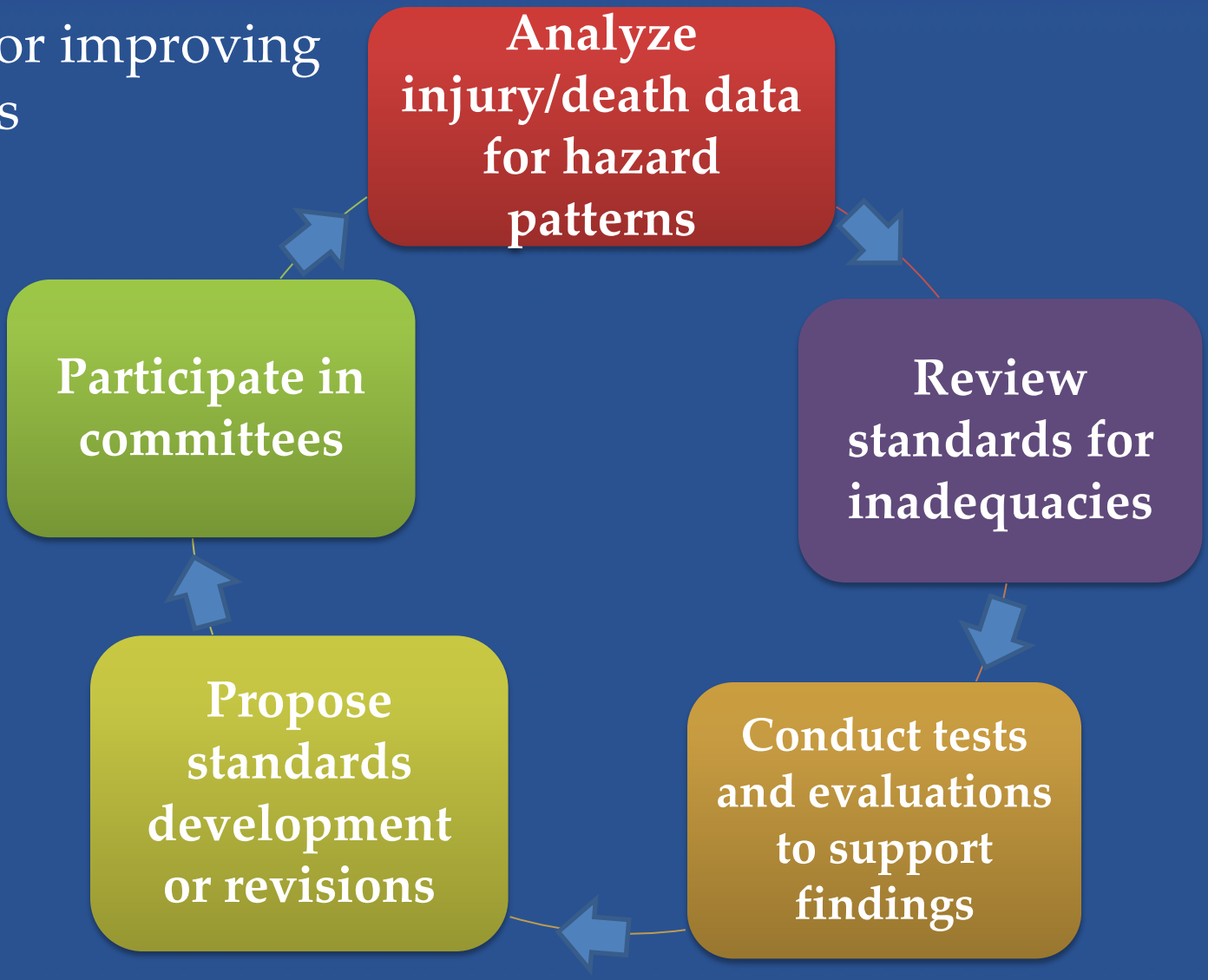
Hazard Identification

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

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- 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

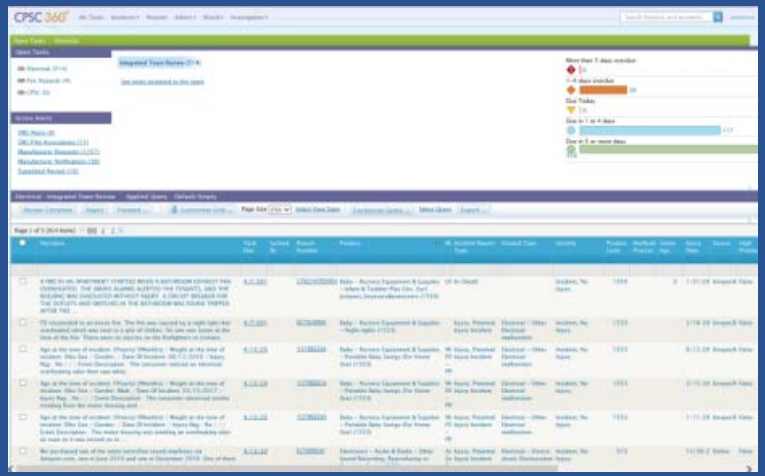
Relevant Voluntary Standards Activity

- 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



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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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

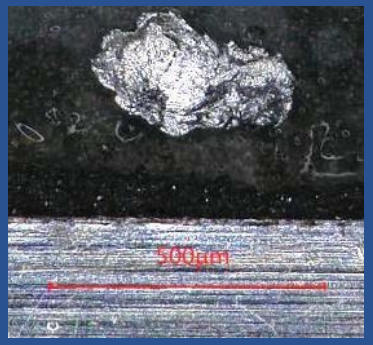
- Root Causes
  - Battery Management System (BMS)
  - Cell Manufacturing quality control (QC)
  - Lack of system integration (Charger-BMS-Cells)
  - Non-Listed cells/systems
- Standards (voluntary or mandatory)
  - Addressable
  - Non-addressable

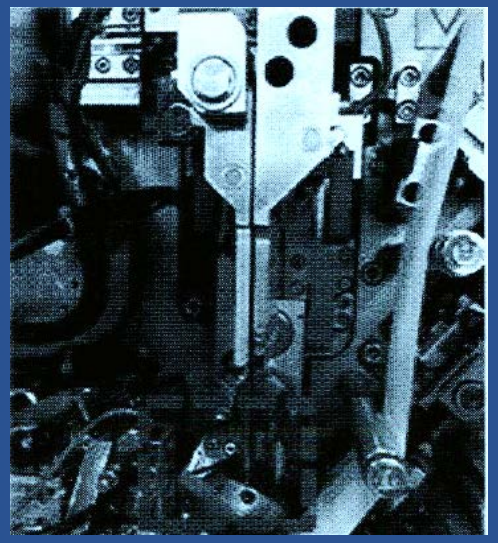
Reasons for Previous Recalls

- 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

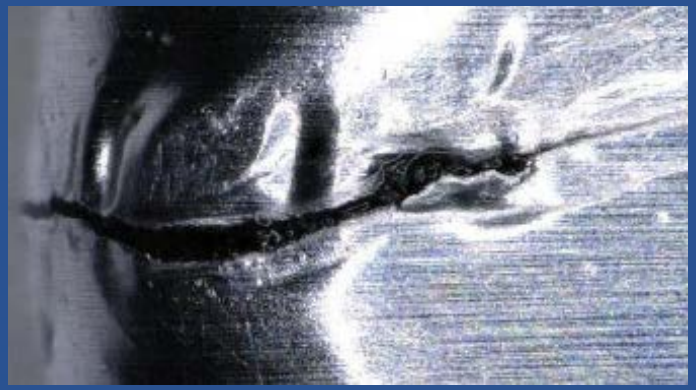
- Root Cause: Chuck was repositioned improperly when interference occurred
- Correct alignment of chuck
- Track assembly line production from affected dates
- Limit scope of recalled products
- Implement process to control further issues with chuck alignment
- Reduce other metal-to-metal processes in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

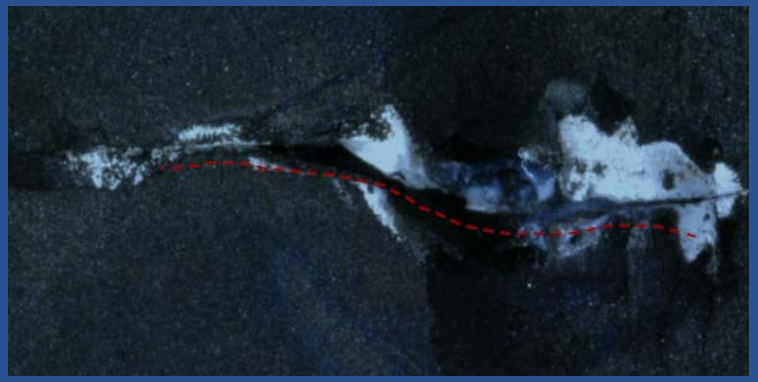
Contamination Mitigation

- 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

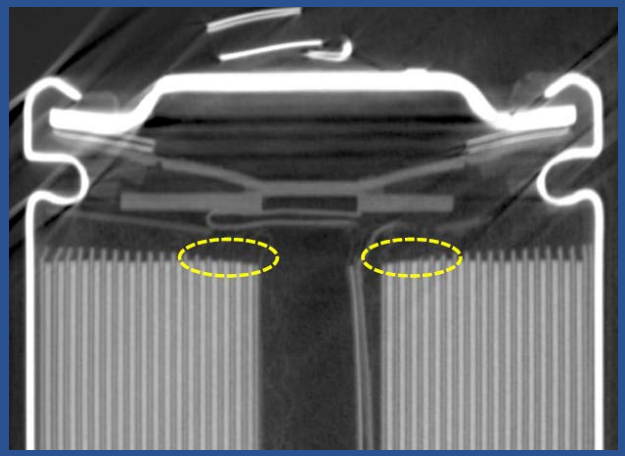
- Damaged outer foil in polymer cell
- Causing internal soft short
- Visual inspections are needed to identify problems and initiate corrective actions before cells leave factory

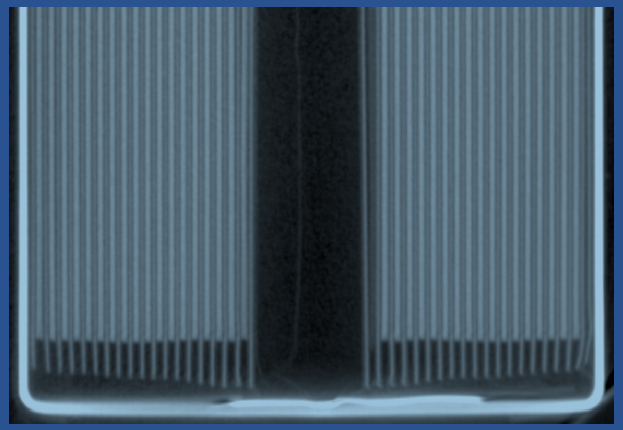




Electrode Alignment

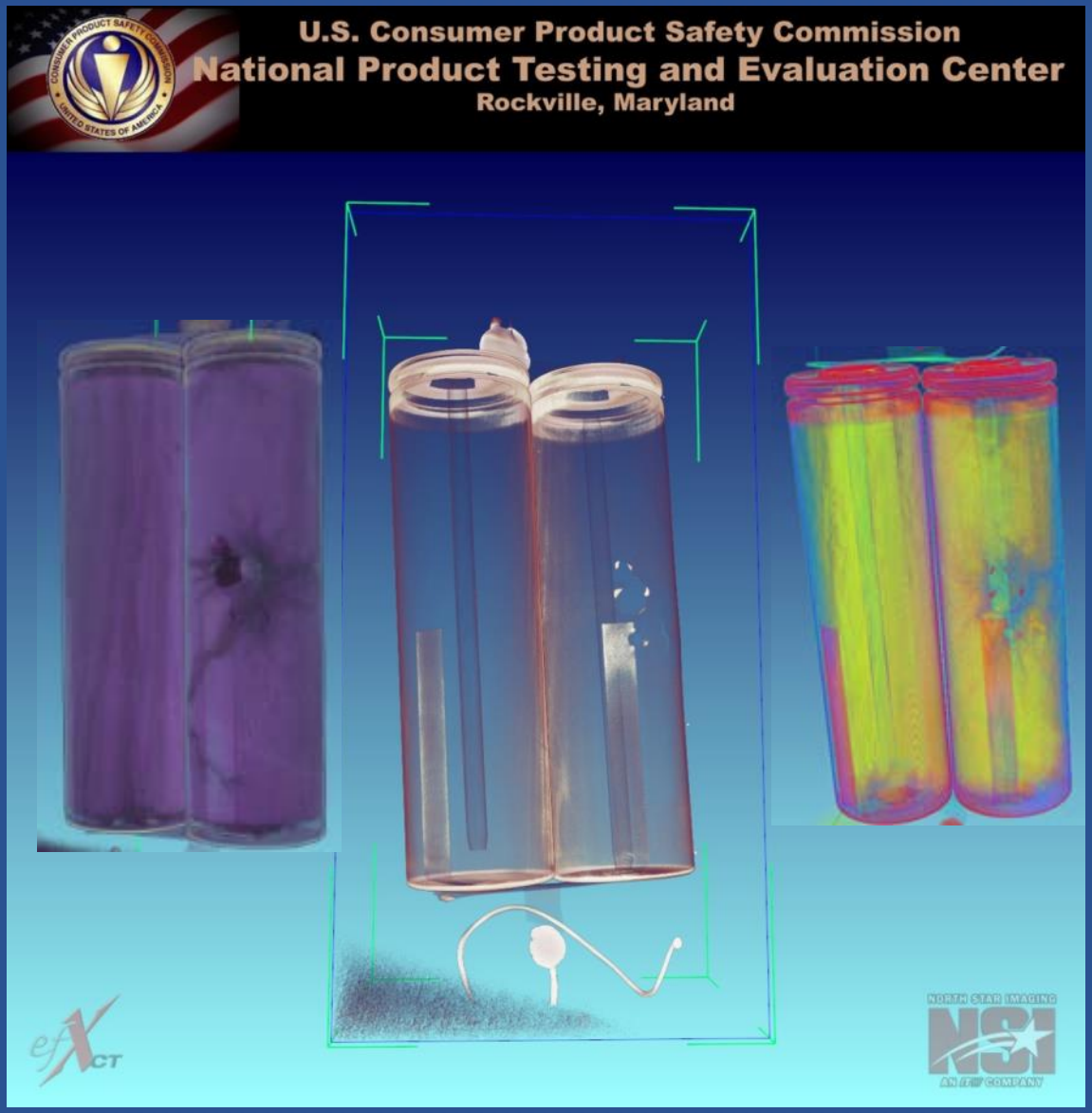
- Sufficient electrode overlap
- Mitigates risks of short circuit from lithium plating on edge
- Negative overlap > 100 μm*





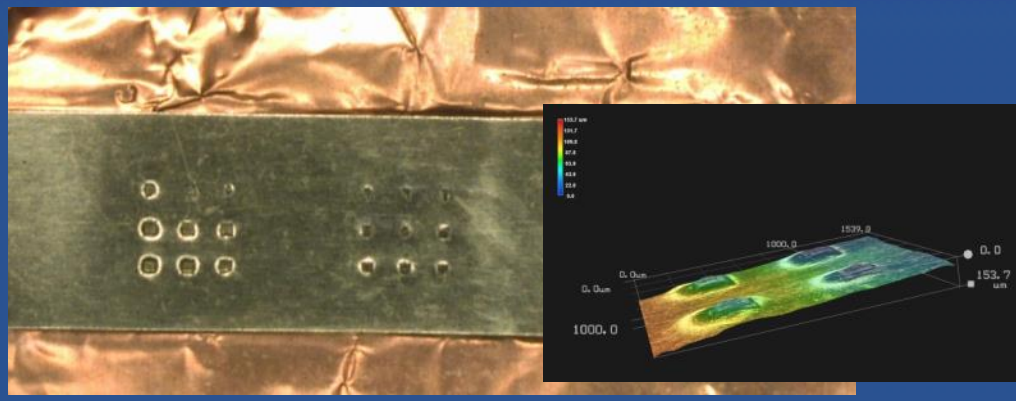
* IEEE 1625 (Laptops) and IEEE 1725 (Cell phones) standards

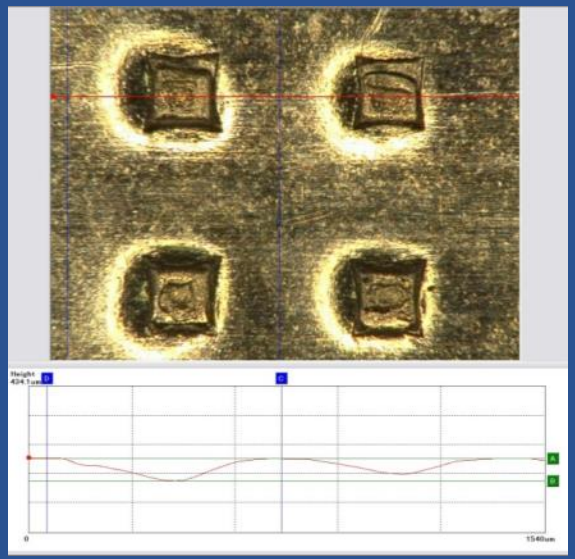
Internal Cell Faults



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

CPSC Staff Ultrasonic Welding Evaluation –Tabs

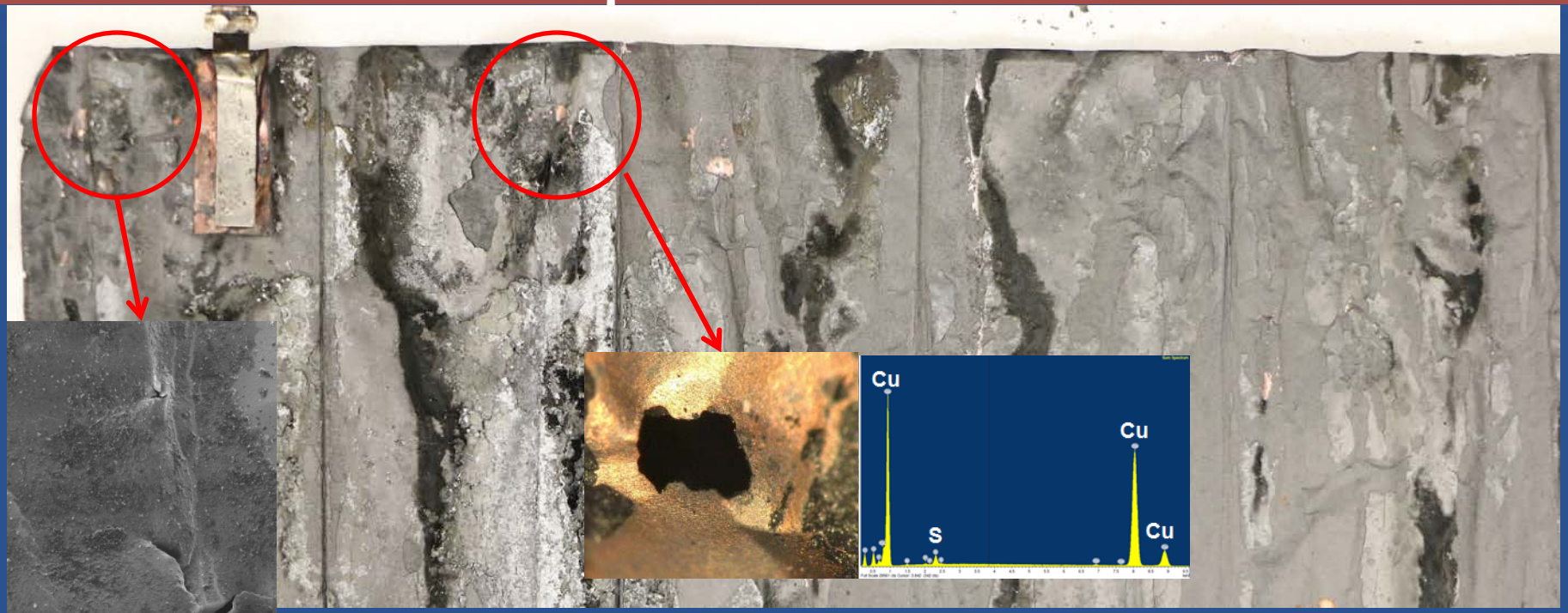




Each Layer thickness

- 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 shorting.

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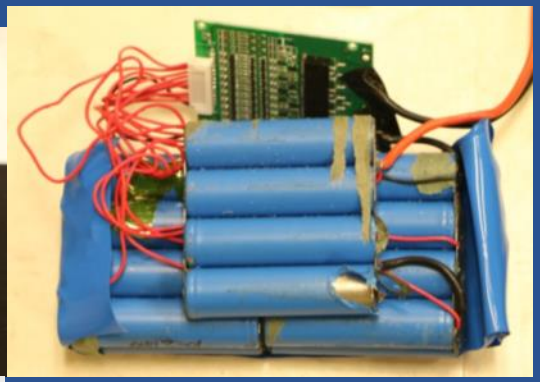
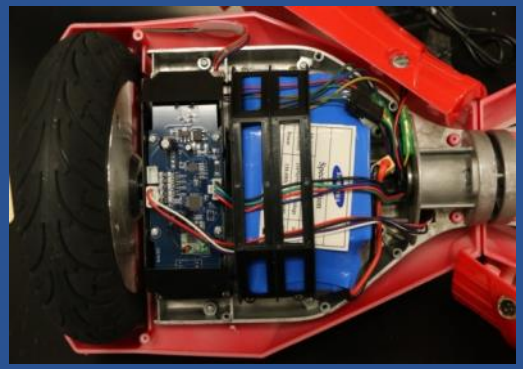
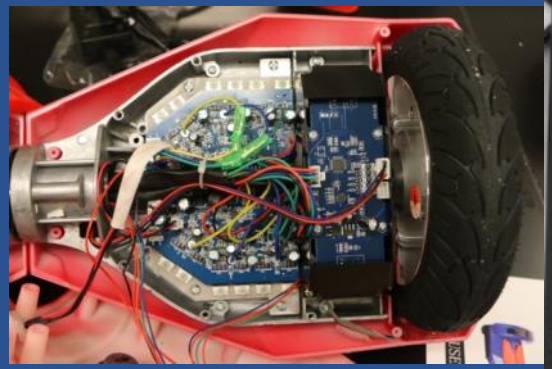
Self-Balancing Electric Scooters or Hoverboards





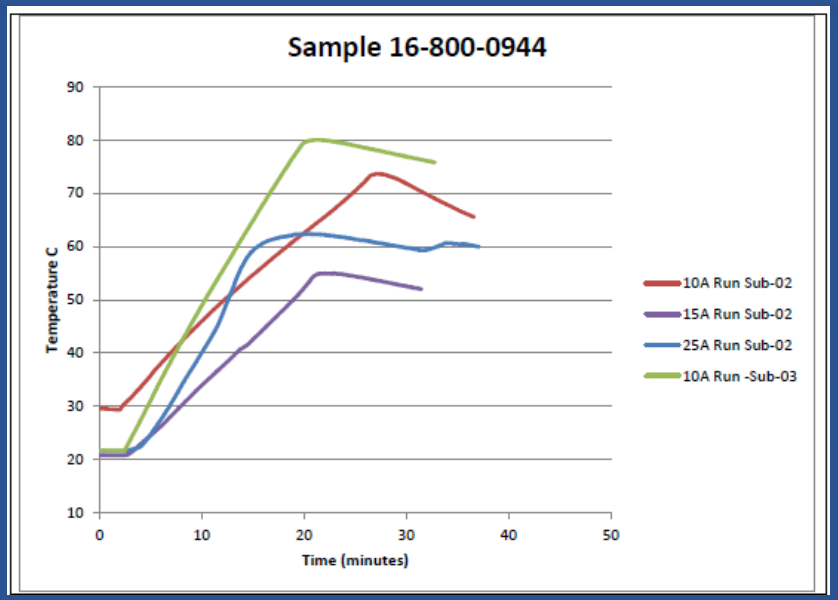


Incidents from Self-Balancing Electric Scooters or Hoverboards

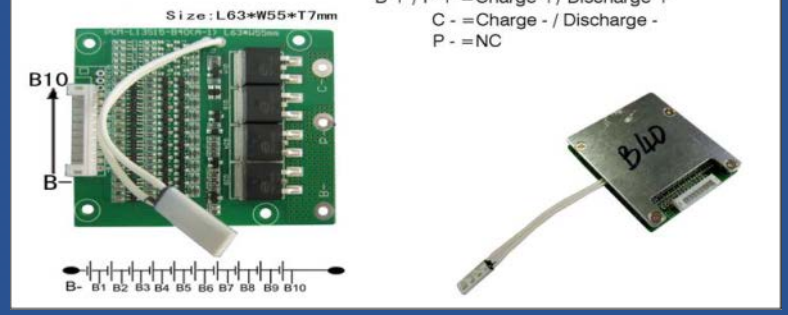
Incidents from Self-Balancing Electric Scooters or Hoverboards

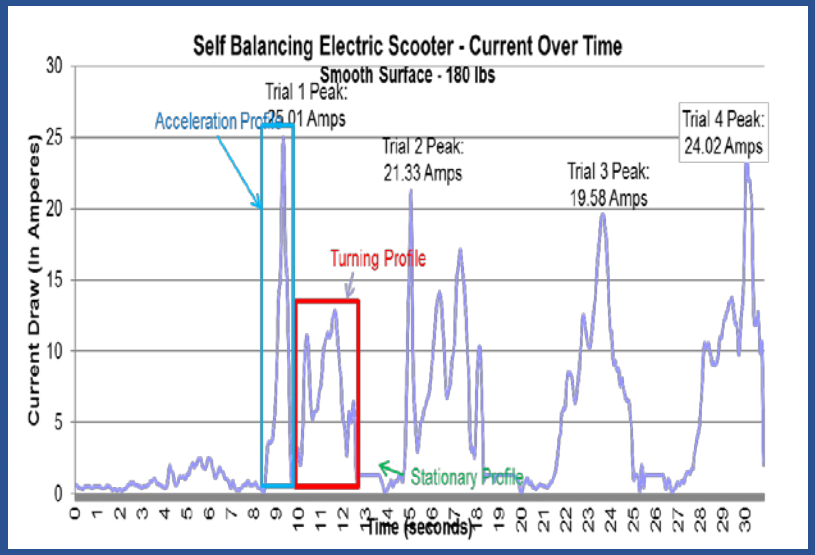
- Over 165 fire incidents, causing over $3M in property damages
  - Incidents occurred in 38 states
  - During and after charging
  - During and after riding
- 3 Deaths –1 fire (2 victims, young girls), 1 fall (MVA death excluded)
- Estimated over 10,000 Emergency Room Visits
  - ~90% from falls, e.g.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

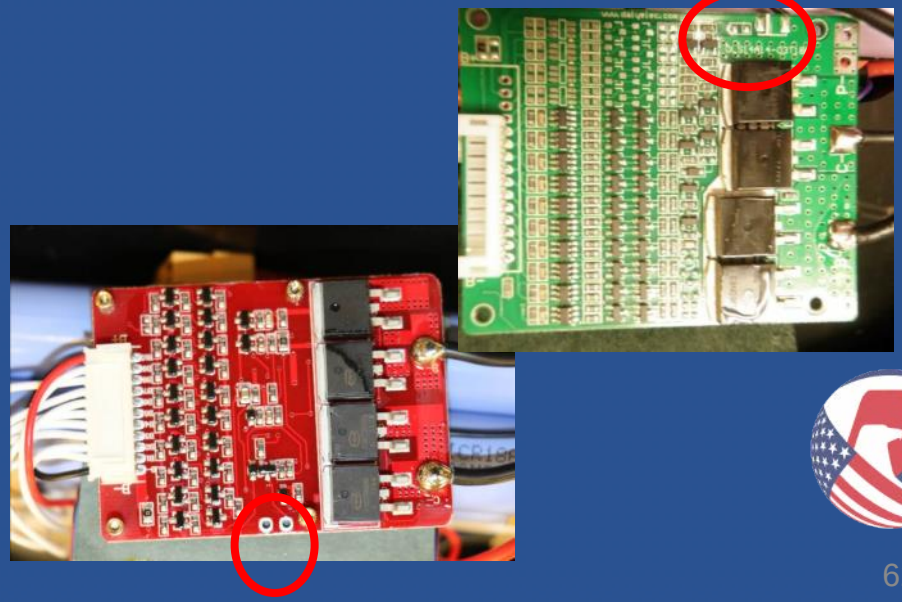
Temperature Management Sensor Not Used



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







Staff Hoverboard Assessment

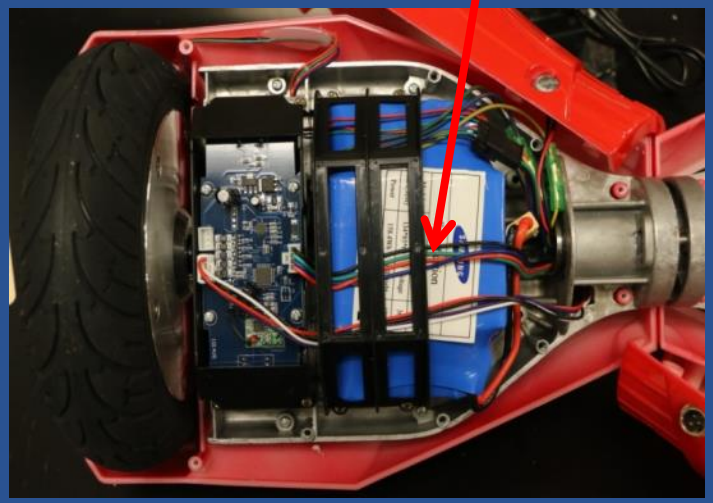
- Staff thoroughly tested and analyzed units on market, found that many used uncertified lithium-ion cells/chargers and did not follow typical safe cell operating practices to protect against operation at excessive temperatures, overcharging or over-discharging.
- Units posed fire hazard.
- Fire incident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

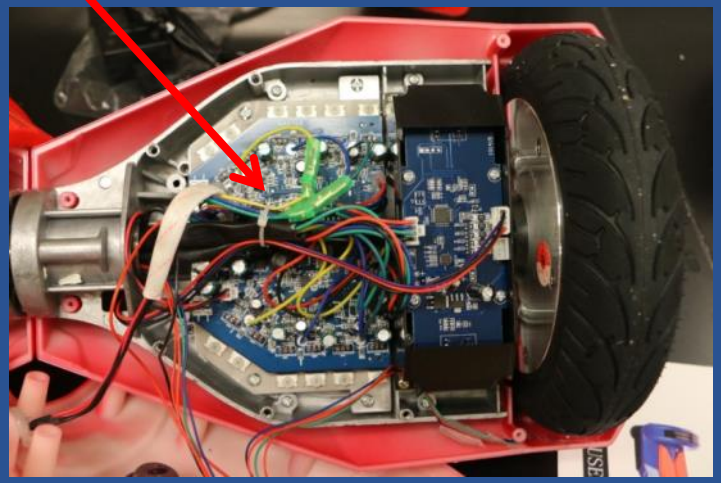
Hoverboard Evaluation Results

- 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

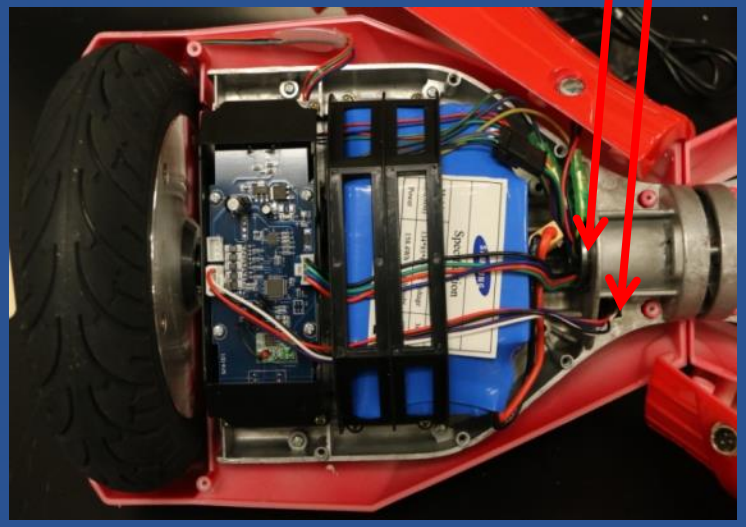
- Wiring throughout hoverboard should be using best practices
  - Securing loose wires
  - Routing wires to prevent stress and cold flow

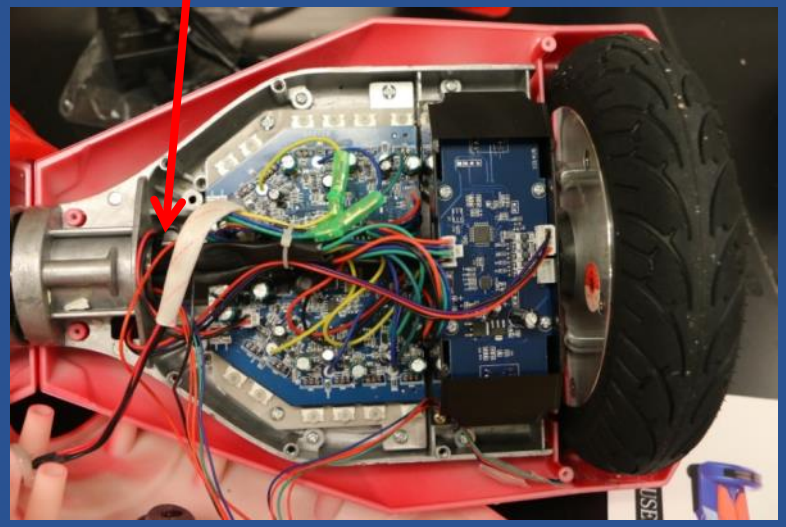




Internal Wiring

- 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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Well-Developed Standards

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

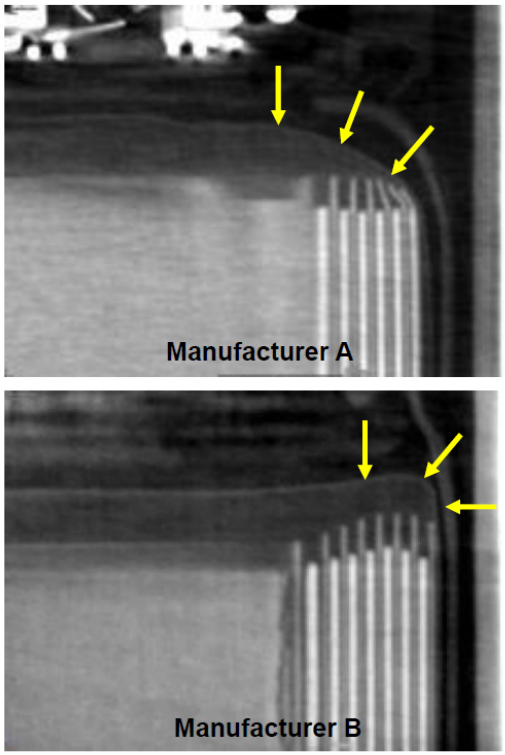
Source: Google images

Manufacturing Design Issue A*

Exponent
Engineering and Scientific Consulting 4

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



* Source: https://news.samsung.com/global/samsung-electronics-announces-cause-of-galaxy-note7-incidents-in-press-conference
(Exponent slides)

Manufacturing QC Issue B*

Exponent
Engineering and Scientific Consulting 6

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

*Source: https://news.samsung.com/global/samsung-electronics-announces-cause-of-galaxy-note7-incidents-in-press-conference
(Exponent slides)

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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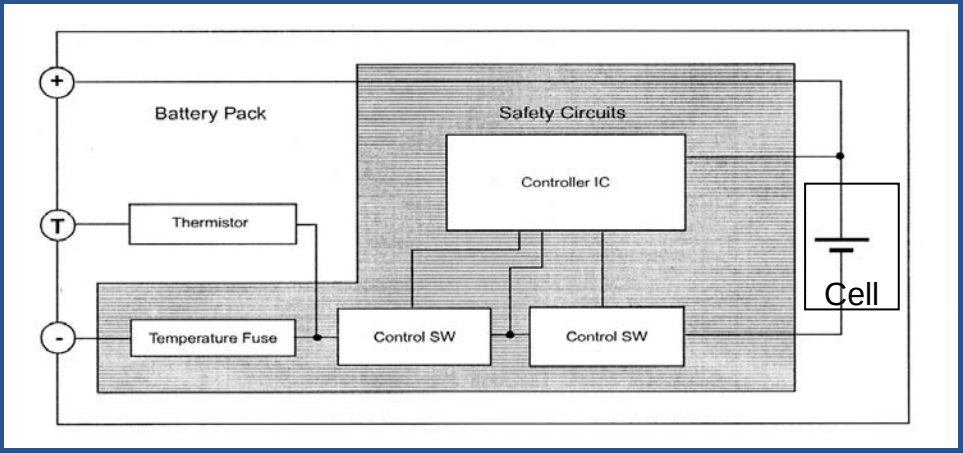
- Lessons Learned – System Safety

Lithium-Ion Battery Safety

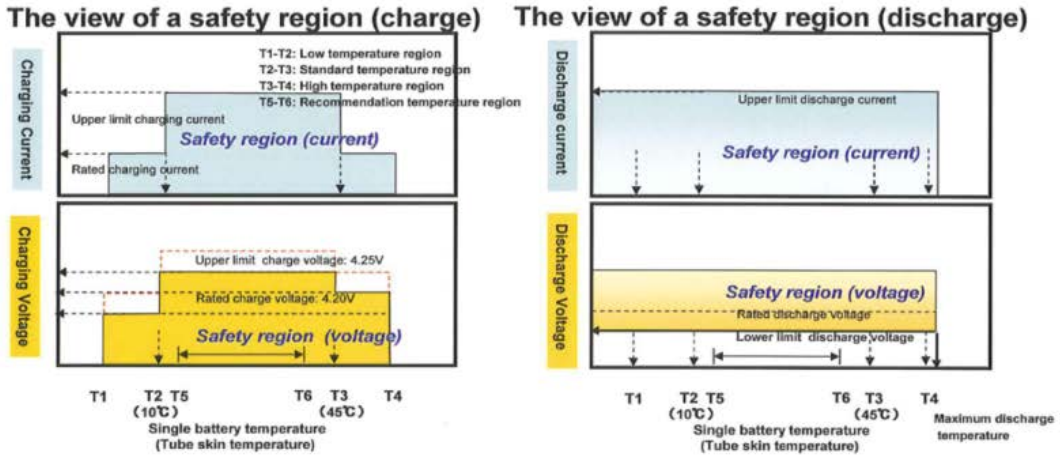
- High energy density – driven by consumer demand
- Electrode chemistries – LCO, LMO, NMC, and LFP
- Flammable electrolytes
- Requires critical safety circuits* to control voltage, current and temperature during charge and discharge

*Safety circuits do not address internal cell shorts



Single-cell battery pack with safety circuits

Guide to Safe Battery Use*



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 °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)

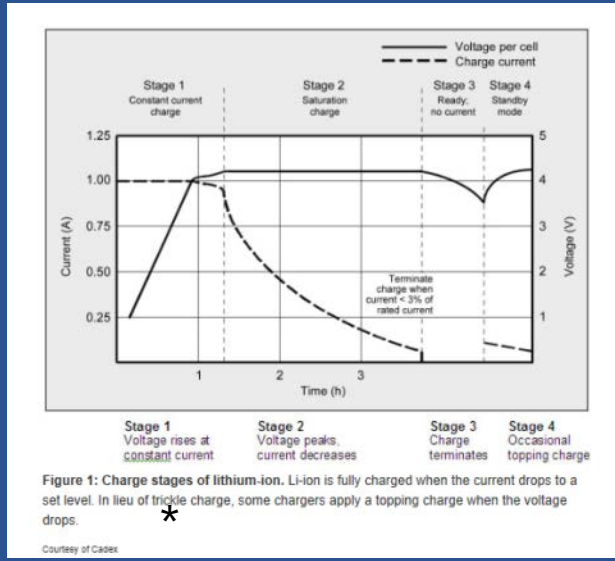


Figure 1: Charge stages of lithium-ion. Li-ion is fully charged when the current drops to a set level. In lieu of trickle charge, some chargers apply a topping charge when the voltage drops.

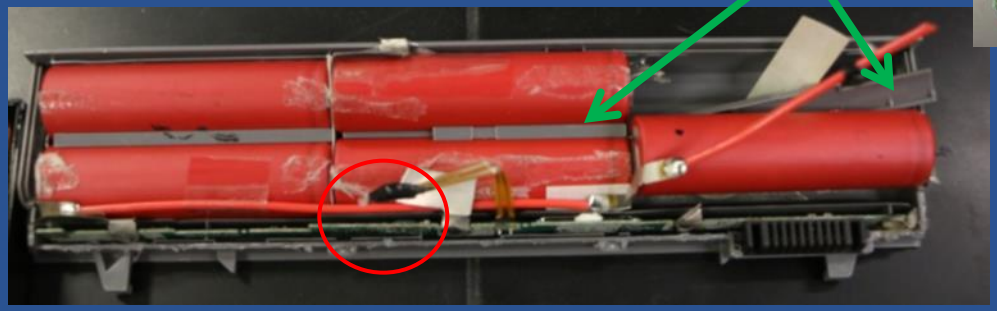
Courtesy of Cadex

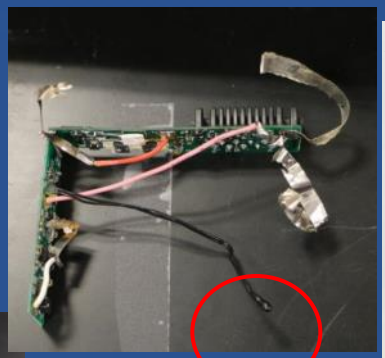
*

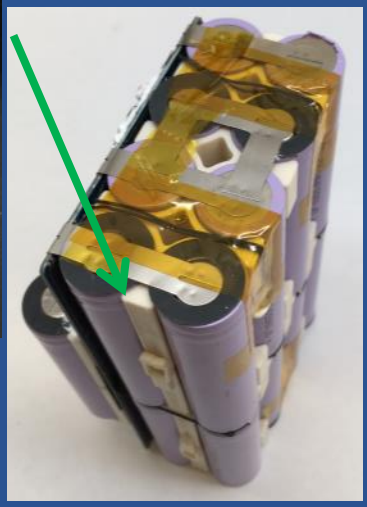
*Source: http://batteryuniversity.com/learn/article/charging_lithium_ion_batteries

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

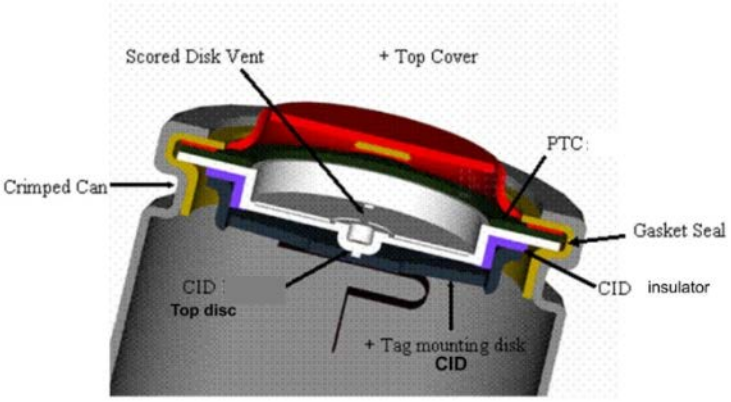


Figure 1. A close-up look at the anatomy of an 18650. Take a look at the different protection devices. By NASA.

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:

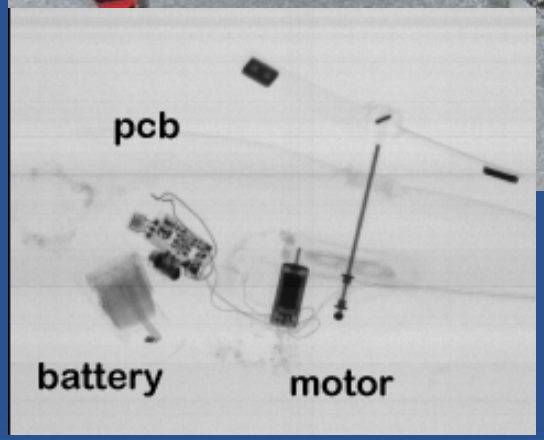
Figure 5. The anatomy of a protected 18650 battery by Lygte Info

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?

Appendix IV: CPSC Presentation at Battery Show North America 2017

U.S. Consumer Product Safety Commission

Lithium-Ion Battery Safety for Consumer Products

September 11, 2017
Battery Show North America 2017

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
- CPSC Battery Project
  - 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
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- Standards

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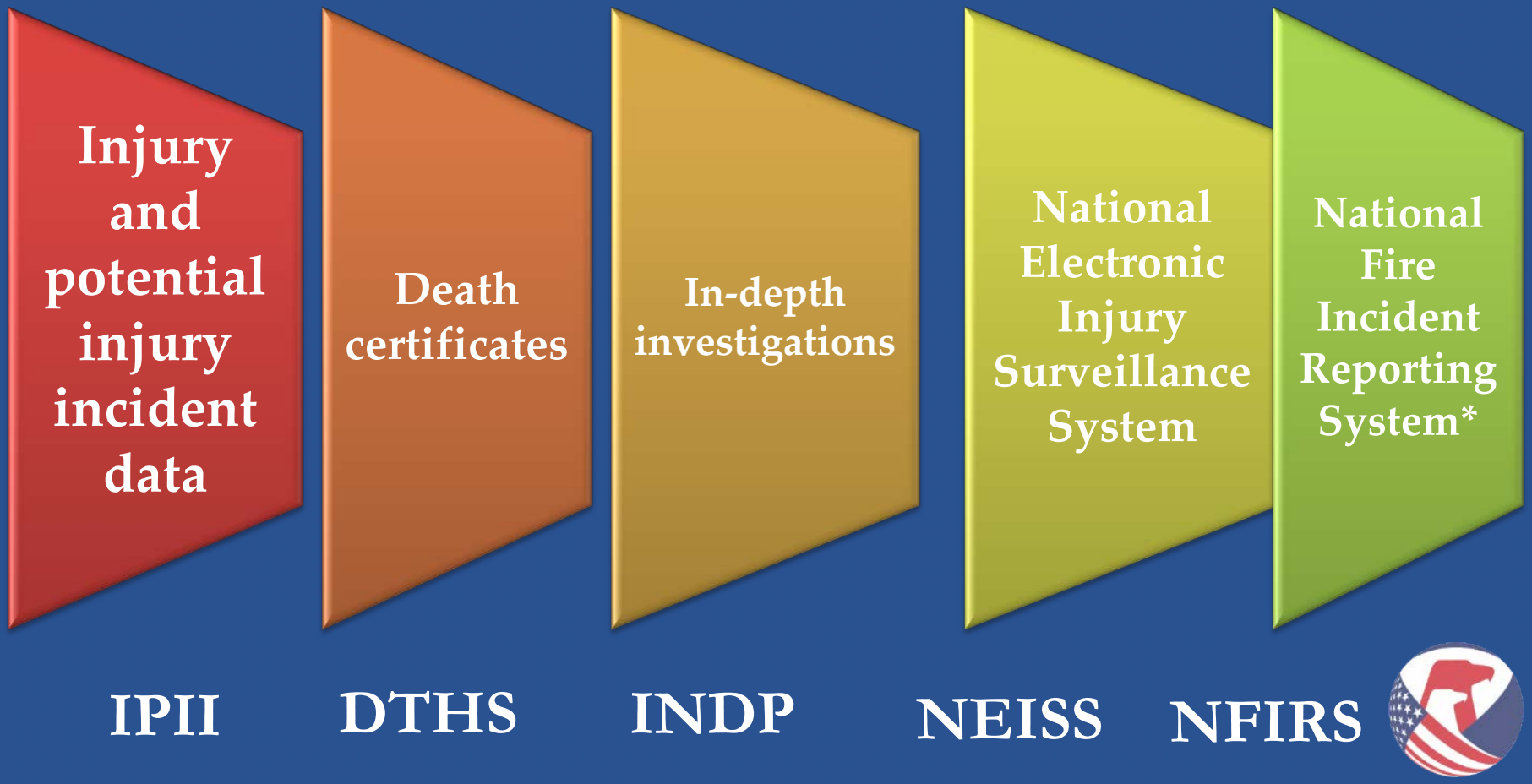
CPSC Data Collection Systems

Staff learns about product-related incidents from five databases



*NFIRS is operated by the United States Fire Administration

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

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

- The Commission may specify "readily observable characteristics" from a consumer product which has substantial compliance with the voluntary standard to reduce the hazard.
- Noncompliance with the "observable requirement" 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

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.

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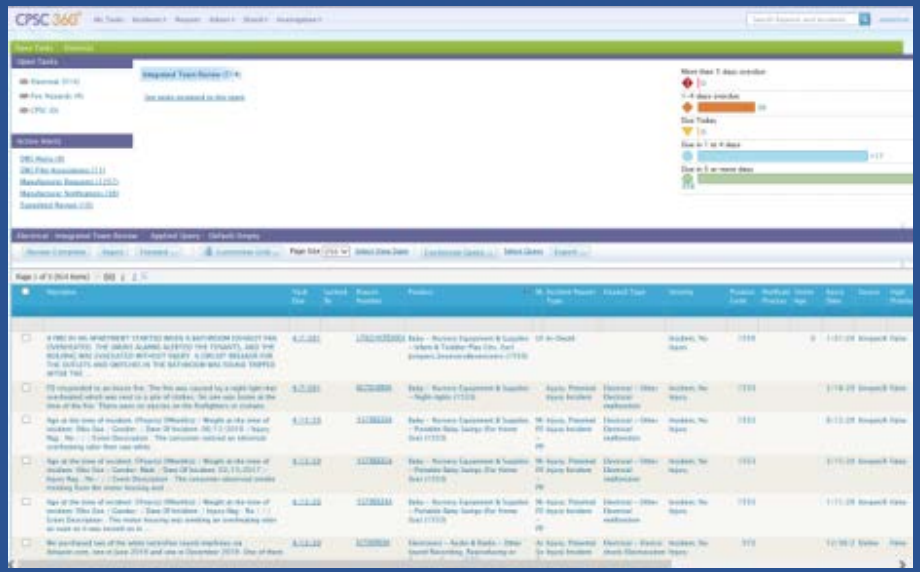
CPSC Battery Project Scope

- 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

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 7/24/17 using Narrative field search terms:

  LI-ION/LITHIUM/POLYMER/BATTER/CHARG
- Results: Over 25,000 incident reports; 483 primary product codes



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

CPSRMS Incident Data (2012-2017)

Product	Number of Incidents
Computer battery or charger	3000
Cell phone battery or charger	2000
Power Banks (Portable USB charger)	400
Drones (under DOT)	200

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
- Injuries by Age (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

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

- 49 Recalls (U.S.) 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

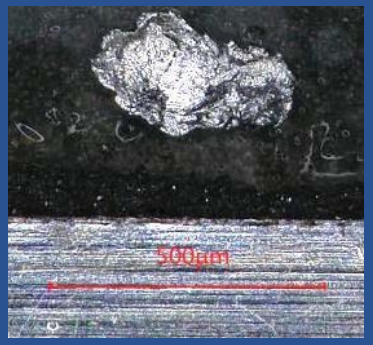
*Other products include baby monitor, gloves, hand warmers, RC car battery pack and wireless speakers

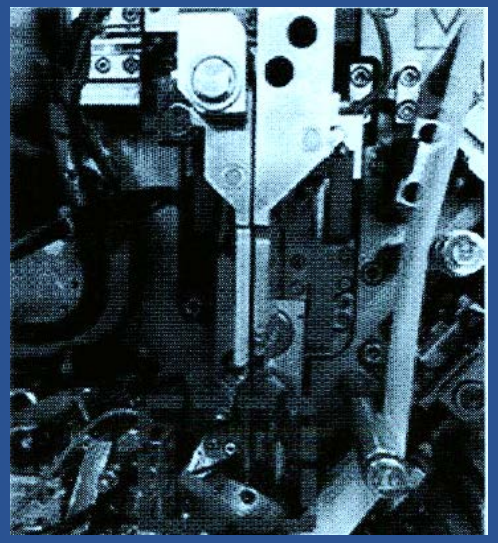
Recalls of Lithium-ion Battery Products

- 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

Cell Contamination

- 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





Cell Contaminant Mitigation

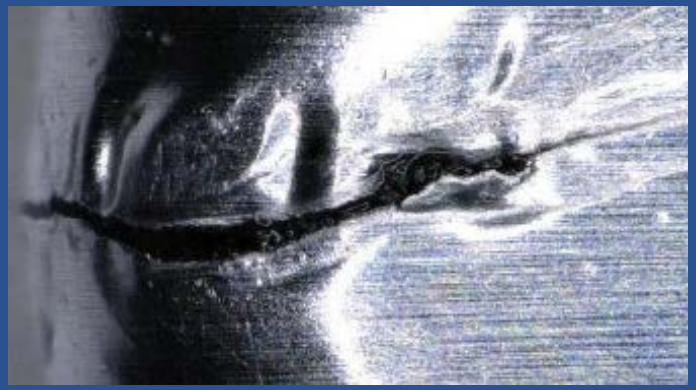
- Root Cause: Chuck was repositioned improperly when interference occurred
- Correct alignment of chuck
- Track assembly line production from affected dates
- Limit scope of recalled products
- Implement process to control further issues with chuck alignment
- Reduce other metal-to-metal processes in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

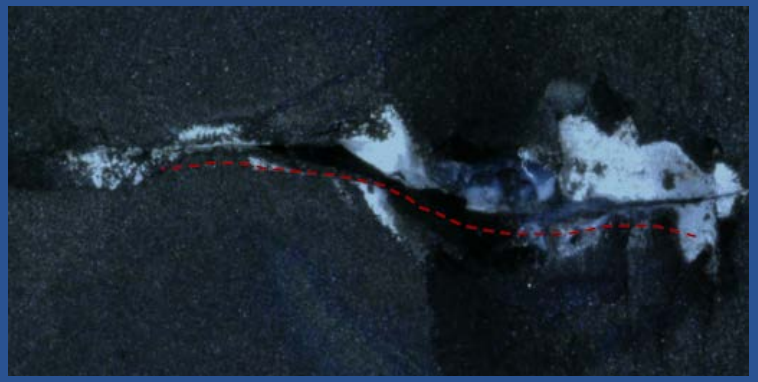
Contamination Mitigation

- 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

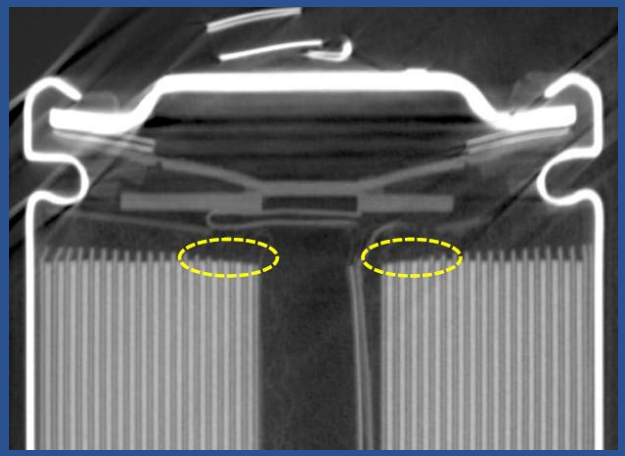
- Damaged outer foil in polymer cell
- Causing internal soft short
- Visual inspections are needed to identify problems and initiate corrective actions before cells leave factory

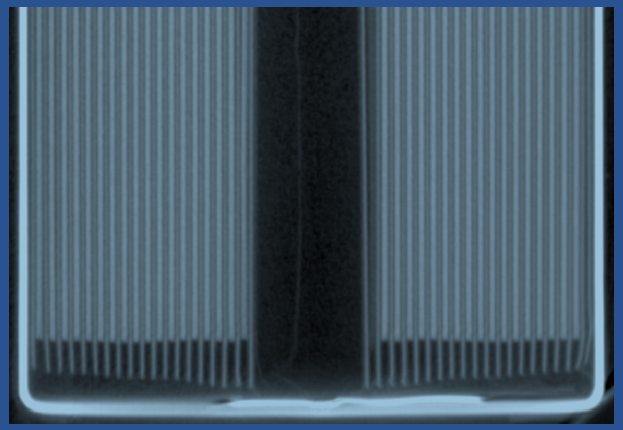




Electrode Alignment

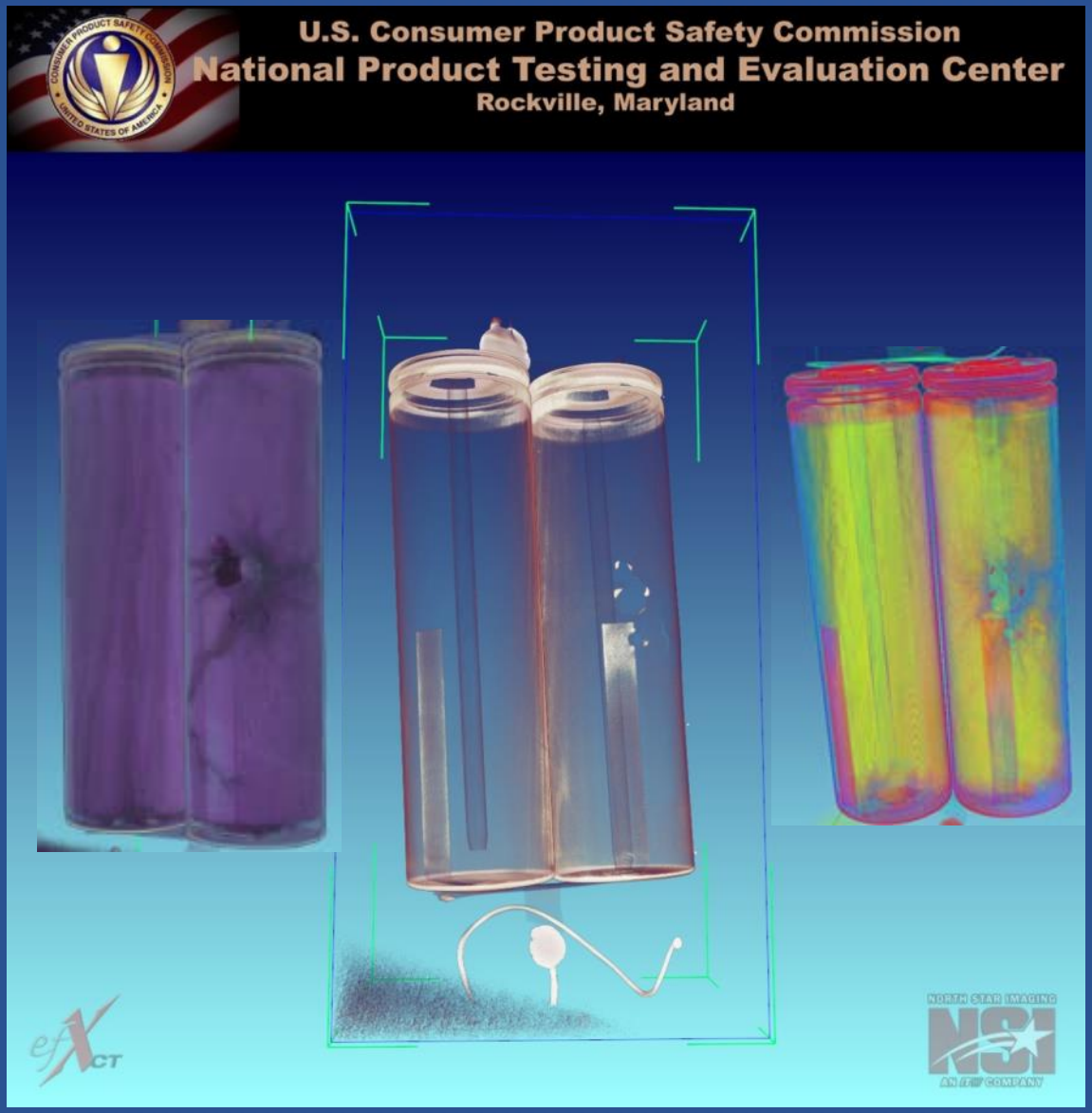
- Sufficient electrode overlap
- Mitigates risks of short circuit from lithium plating on edge
- Negative overlap > 100 µm*





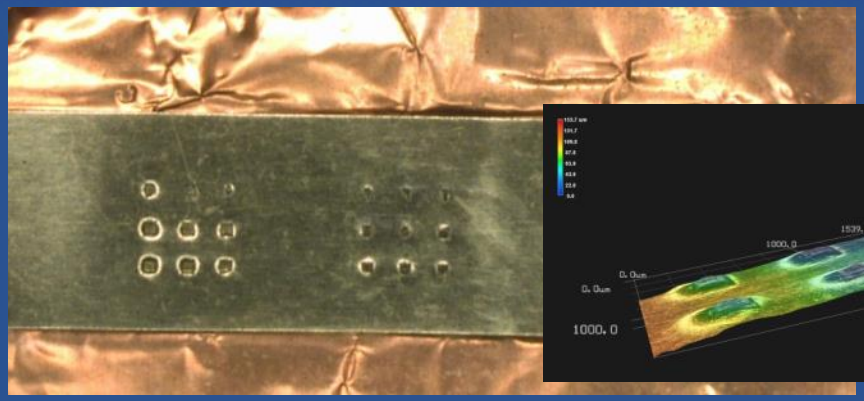
* IEEE 1625 (Laptops) and IEEE 1725 (Cell phones) standards

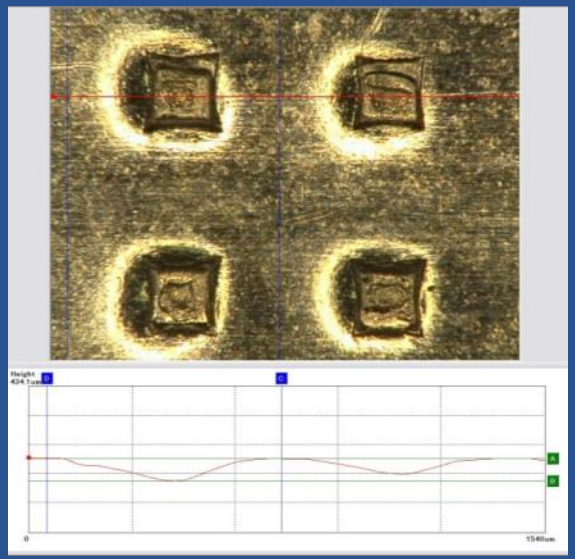
Internal Cell Faults



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

CPSC Staff Ultrasonic Welding Evaluation –Tabs

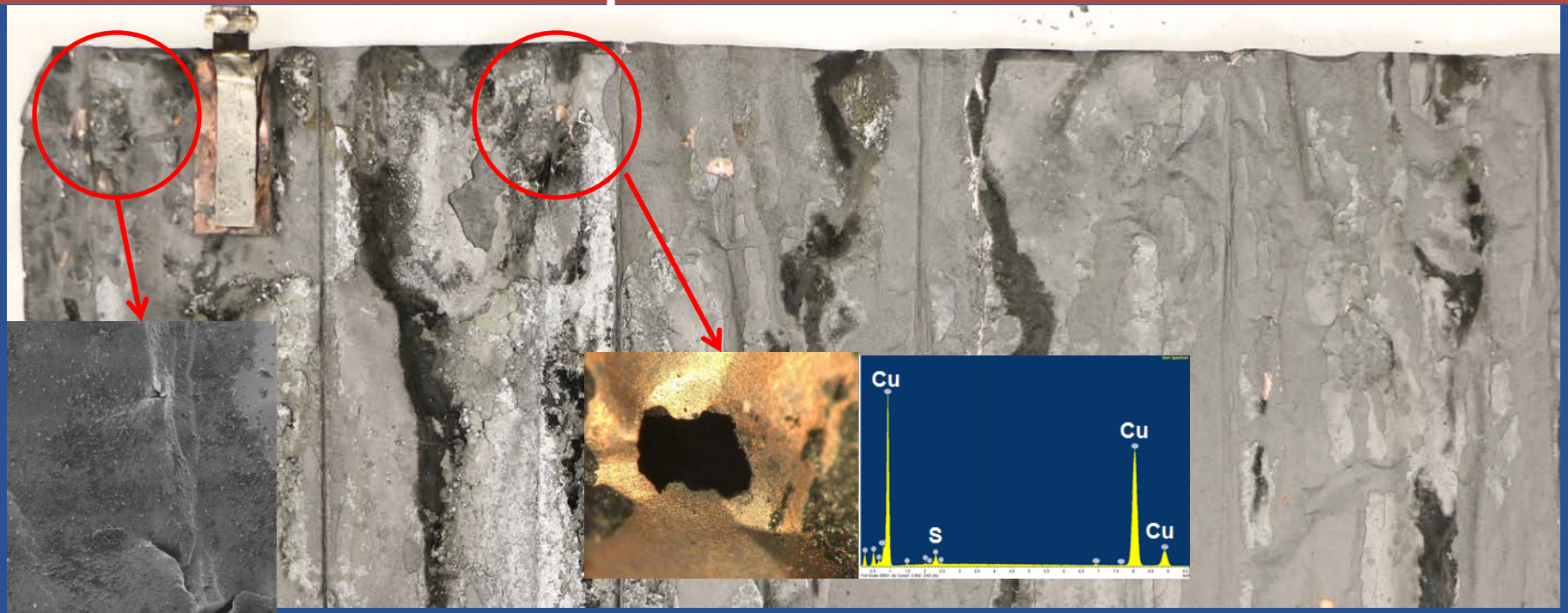




Each Layer thickness

- 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 shorting.

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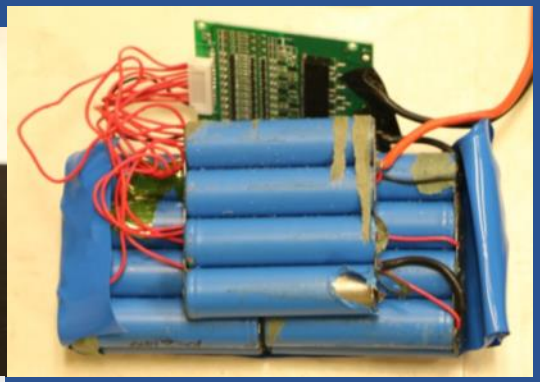
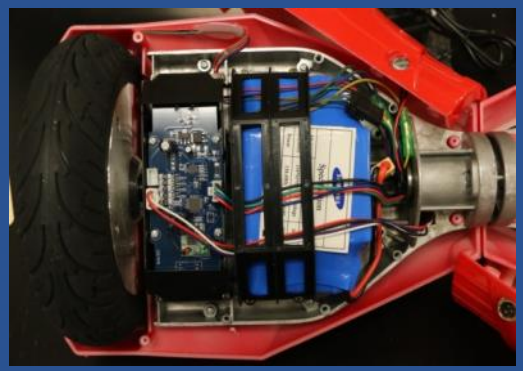
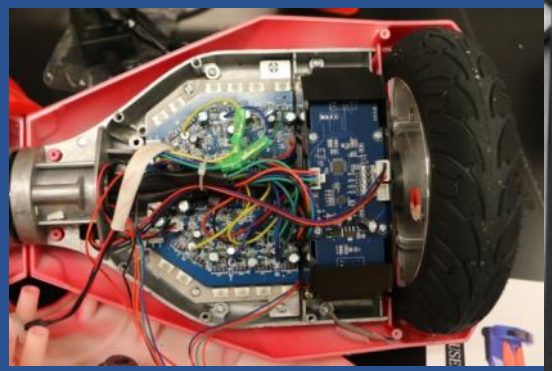
Self-Balancing Electric Scooters or Hoverboards





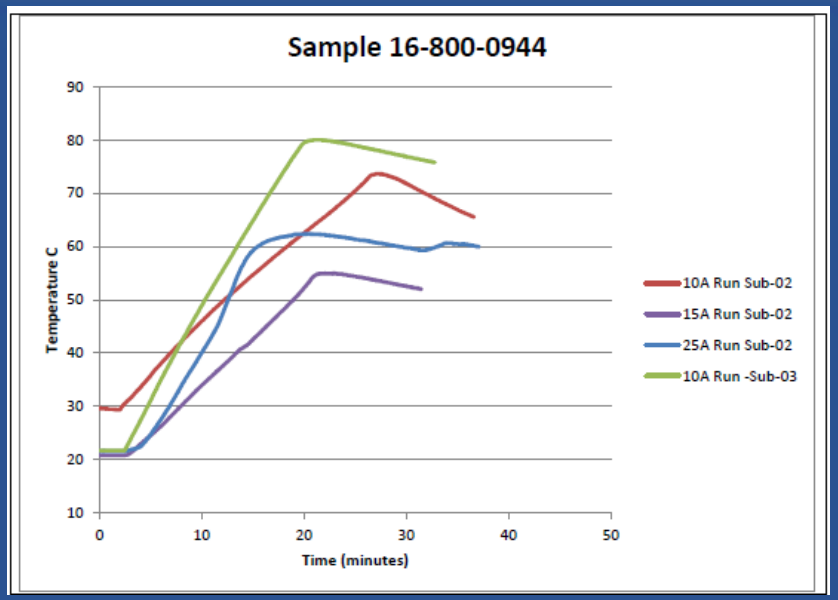


Incidents from Self-Balancing Electric Scooters or Hoverboards

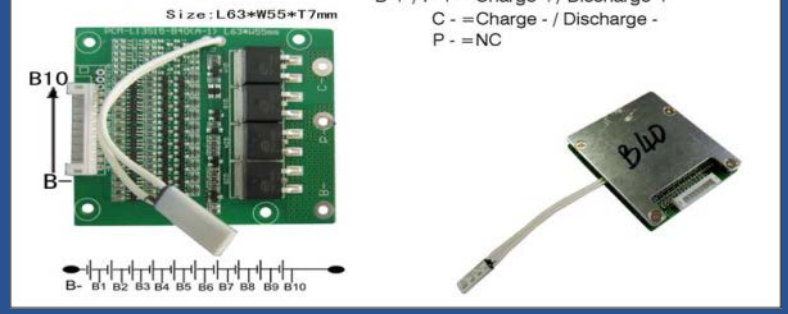
Incidents from Self-Balancing Electric Scooters or Hoverboards

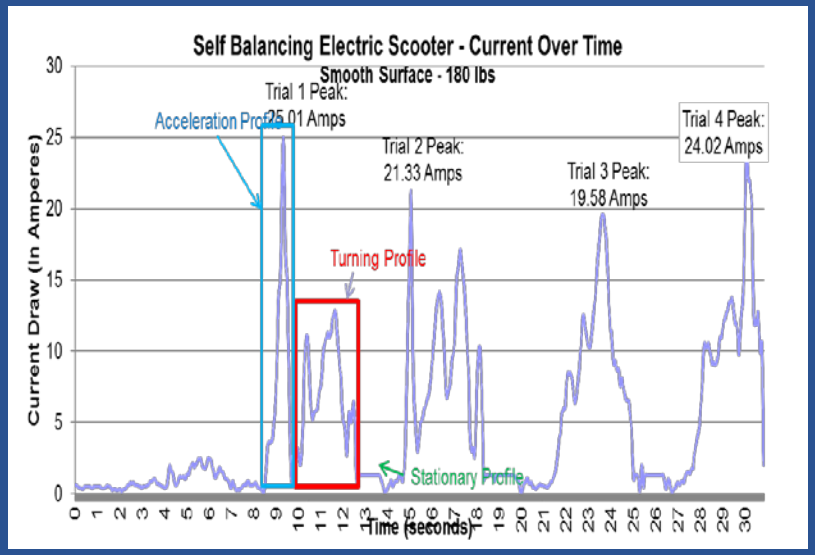
- Over 200 fire incidents since 2015, causing over $4M in property damages
  - Incidents occurred in 43 states
  - During and after charging
  - During and after riding
- 3 Deaths –1 fire (2 victims, young girls), 1 fall
  (First responder motor vehicle death excluded)
- Estimated over 10,000 Emergency Room Visits
  - ~90% from falls, e.g. sudden stops and starts
  - ~15% head injuries
  - ~50% arm injuries
  - ~40% fractures
  - ~30% sprain/abrasions

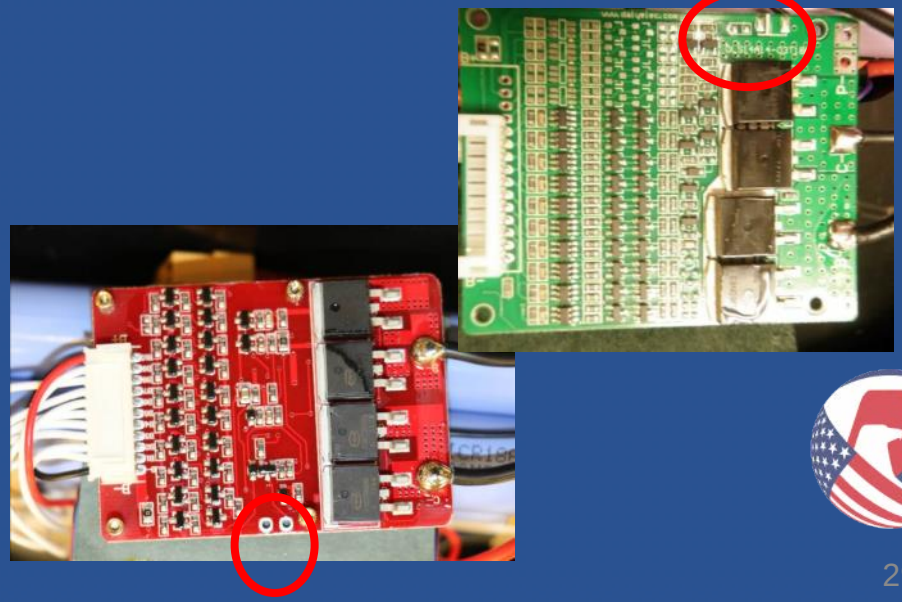
Temperature Management Sensor Not Used



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





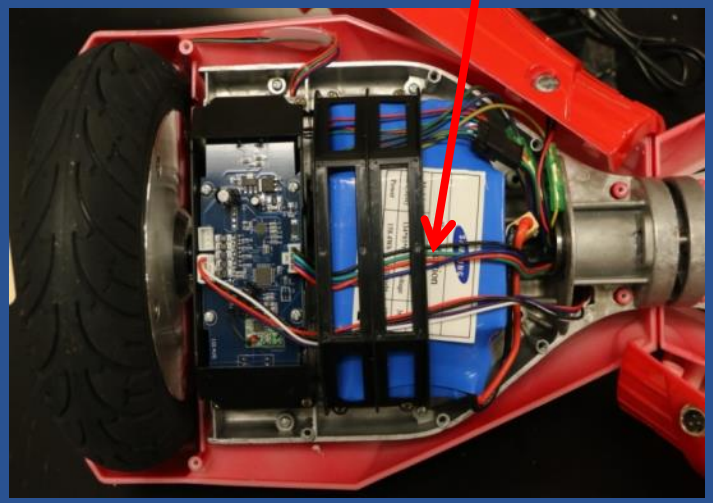


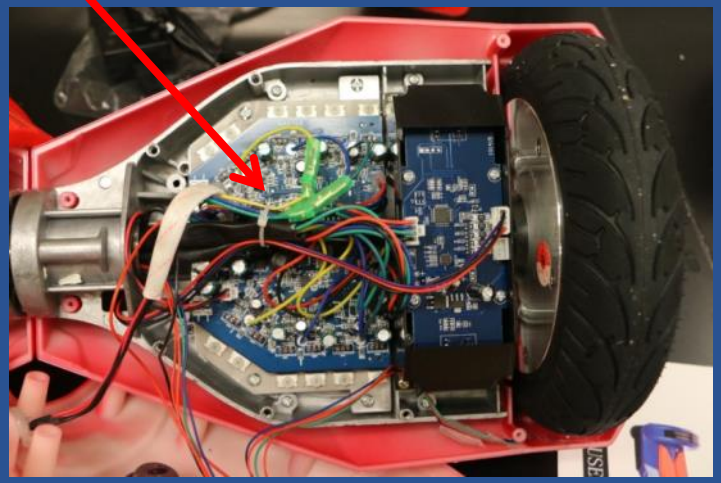
Hoverboard Evaluation Results

- 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

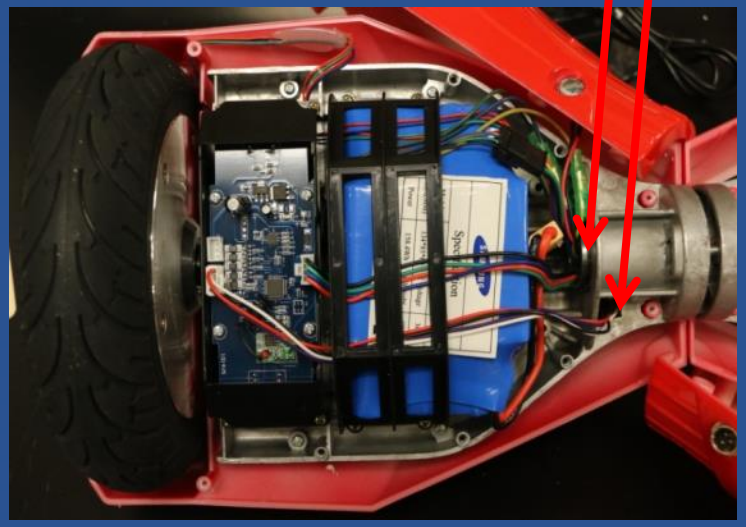
- Wiring throughout hoverboard should be using best practices
  - Securing loose wires
  - Routing wires to prevent stress and cold flow

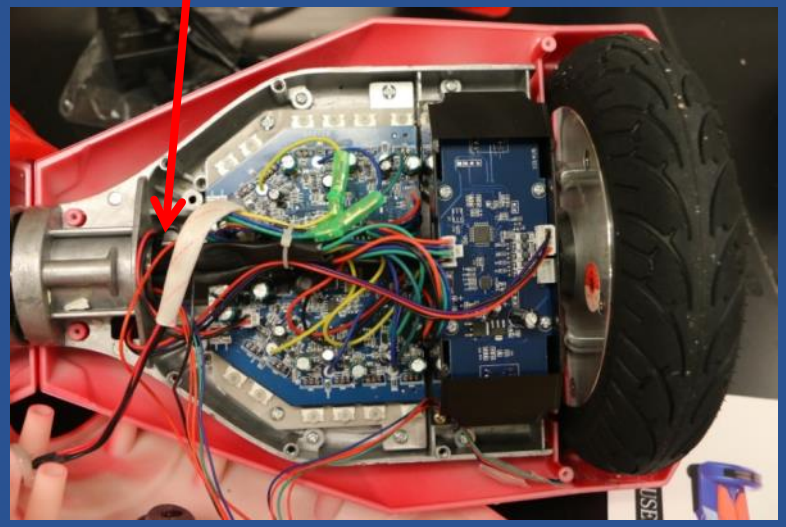




Internal Wiring

- 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

Outline

Part 1: Data

- Basics on CPSC 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
- Standards

Well-Developed Standards

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

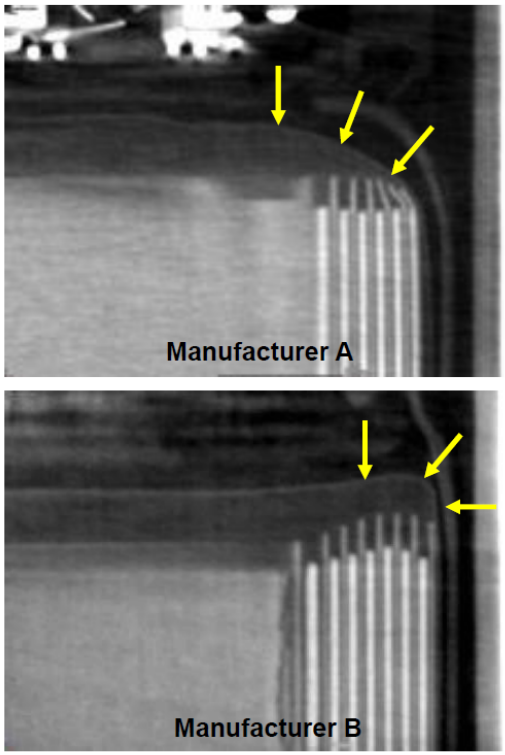
Source: Google images

Manufacturing Design Issue A*

Exponent
Engineering and Scientific Consulting 4

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



* Source: https://news.samsung.com/global/samsung-electronics-announces-cause-of-galaxy-note7-incidents-in-press-conference
(Exponent slides)

Manufacturing QC Issue B*

Exponent
Engineering and Scientific Consulting 6

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

*Source: https://news.samsung.com/global/samsung-electronics-announces-cause-of-galaxy-note7-incidents-in-press-conference
(Exponent slides)

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)
  - (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

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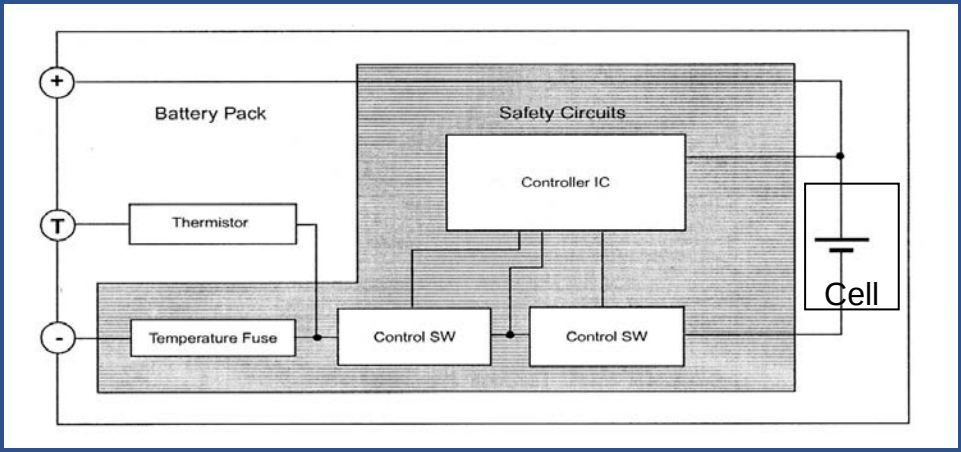
Lithium-Ion Battery Safety

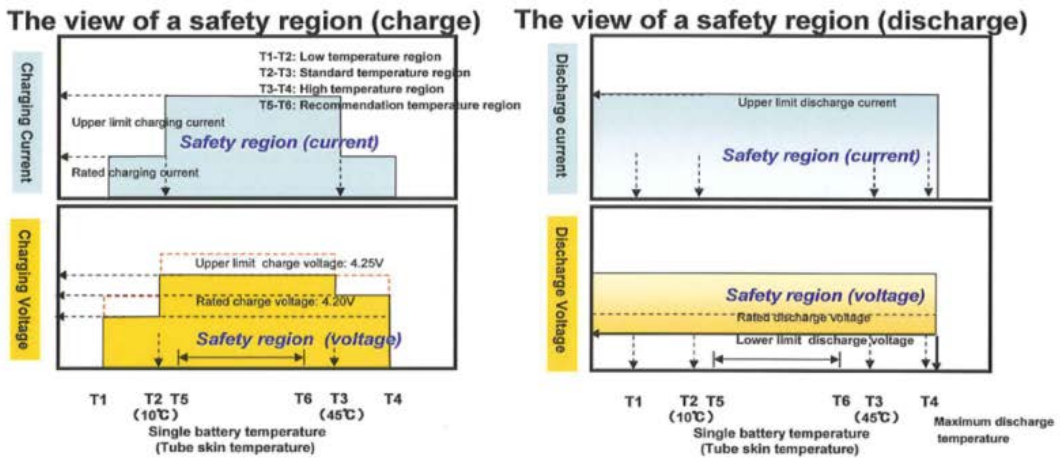
- High energy density – driven by consumer demand
- Electrode chemistries – LCO, LMO, NMC, and LFP
- Flammable electrolytes
- Requires critical safety circuits* to control voltage, current and temperature during charge and discharge

*Safety circuits do not address internal cell shorts



Single-cell battery pack with safety circuits

Guide to Safe Battery Use*



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 °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)

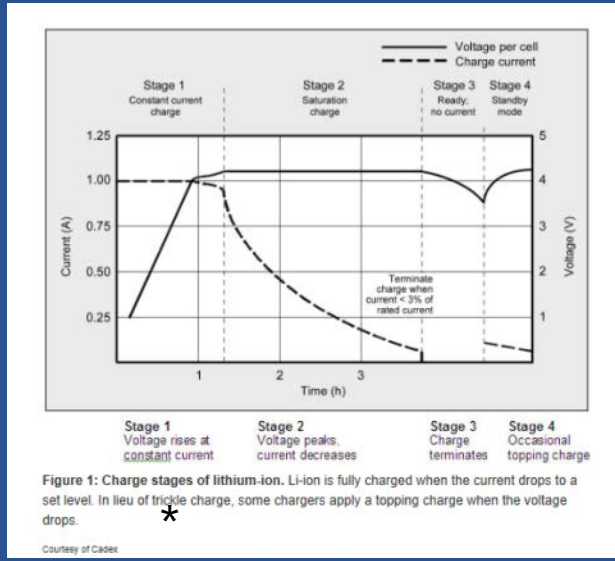


Figure 1: Charge stages of lithium-ion. Li-ion is fully charged when the current drops to a set level. In lieu of trickle charge, some chargers apply a topping charge when the voltage drops.

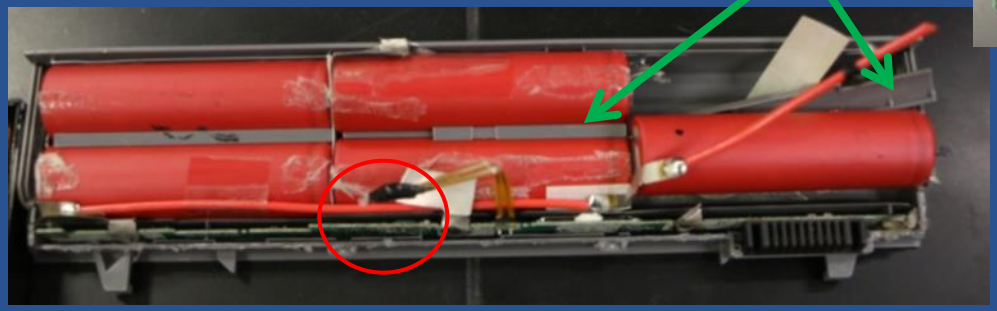
Courtesy of Cadex

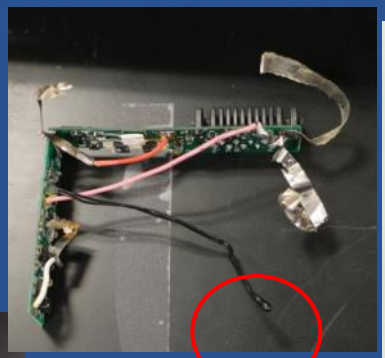
*

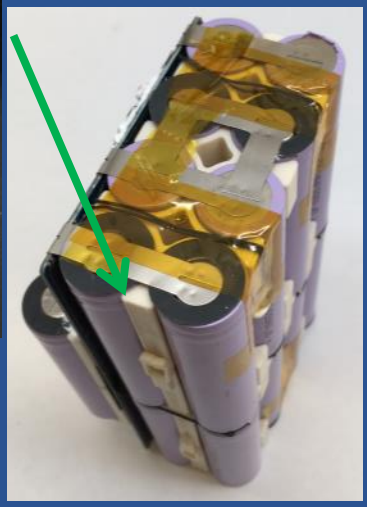
*Source: http://batteryuniversity.com/learn/article/charging_lithium_ion_batteries

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

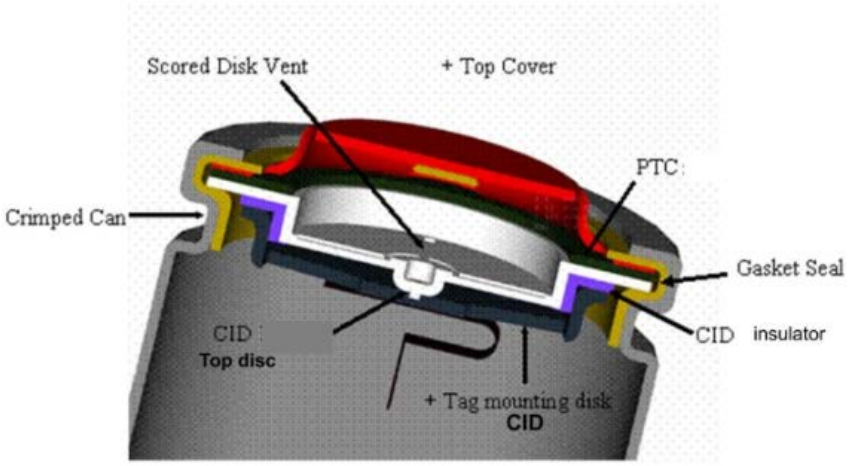


Figure 1. A close-up look at the anatomy of an 18650. Take a look at the different protection devices. By NASA.

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

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

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

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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*

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

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

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