

Transcript of 2021 CPSC Podcast Series, “Overview of Battery Safety Requirements”

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The slides used in this podcast are not a comprehensive statement of legal requirements or policy, and thus, should not be relied upon for that purpose. You should consult official versions of U.S. statutes and regulations, as well as published CPSC guidance, when making decisions that could affect the safety and compliance of products entering U.S. commerce. Note that references are provided at the end of the presentation.

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Hi, my name is Sylvia Chen, and I want to welcome you to this podcast presentation today.

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As stated before: “design of safe products at the outset is critical.” CPSC is a United States federal government agency charged with protecting the public from unreasonable risks of injury or death associated with the use of consumer products under the agency’s jurisdiction. We have developed this podcast series not only to inform about regulations, standards, and other safety requirements, but also to emphasize the importance of designing products with safety considerations in mind, and to offer best practices for enhancing the safety of a variety of common consumer products.

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The series covers six common consumer products and the requirements for keeping consumers safe, focusing on products affecting millions of consumers, such as children’s sleepwear, wearables, batteries, gates and enclosures, micromobility, and cribs and play yards. In this podcast series, you can expect to learn about the key hazards and risks of the product, important design and manufacturing considerations, regulations and standards that CPSC uses to ensure product safety, best practices you can employ, and what resources are available to assist you in understanding and implementing the requirements.

The podcasts include English and Chinese slide decks and Chinese narration to make this important safety information as accessible as possible. Additionally, CPSC has established a dedicated email box, where listeners, at their convenience, can send in any questions, in English or Chinese. Our staff will monitor the email box and respond to your questions. Transcripts in English are available on this site.

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And now, I would like to introduce the presenter, Joseph Tsai, a Senior Compliance Officer in the CPSC's Office of Compliance and Field Operations.

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The following presentation will cover the U.S. Consumer Product Safety Commission technical staff's efforts to ensure electrical product safety, our work on lithium battery safety, and recommendations for best practices to manufacture lithium-ion cells and battery-powered products to minimize safety risks.

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Electricity is a powerful, useful energy source that is potentially hazardous.

Product failures or misuse can cause fires, electric shock, thermal burns from touching a hot surface, chemical burns, such as from electrolytes leaking from a battery, injuries like lacerations from moving parts or loss of critical function, such as a smoke alarm that does not sound during a fire.

Equipment that generates, distributes, or uses electrical energy should be compliant with applicable mandatory and industry consensus standards and installed according to applicable electrical codes to mitigate safety risks.

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CPSC staff estimates that between 2013 and 2015, U.S. fire departments responded to an annual average 67,900 structure fires caused by faulty electrical equipment, resulting in 660 deaths, 3,410 injuries, and \$1.738 billion in property losses each year. The top three electrical causes of fires are cooking equipment, which includes ranges and ovens, microwave ovens and small appliances; electrical distribution system equipment, which includes installed wiring, receptacles, and switches; and heating and cooling equipment.

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Between 2004 and 2013, CPSC staff estimates 60 product-related electrocution deaths. The top four product categories to which these incidents were attributed were large appliances, small appliances, power tools, and lighting equipment. Electrocutions have declined over time, with increases in products incorporating double insulation and battery power, and with the implementation of ground-fault circuit interrupters.

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CPSC staff uses a multipronged approach to mitigate safety risks, such as supporting improvements to industry consensus standards/codes, distributing safety information to consumers, creating and enforcing technical regulations and bans, and recalling products with

defects after identifying hazards through investigations. This podcast will cover standards, standard compliance, and recalls.

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Staff relies on electrical products being in compliance with industry consensus standards to ensure minimum levels of safety

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).

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If a current industry consensus standard is not likely to adequately reduce the risk of injury, or if manufacturers are not likely to substantially comply with the consensus standard, then CPSC statutes allow the Commission to address the risk of injury by creating a technical regulation.

Check the CPSC website, or contact CPSC staff to determine what requirements your product must meet: <https://www.cpsc.gov/Business--Manufacturing>. Battery-operated toys, electric toys, and citizens band (CB) station antennas are some electrical products subject to technical regulations.

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For battery-operated toys the technical regulation is ASTM F963-17, The Standard Consumer Safety Specification for Toy Safety, which is a comprehensive standard addressing numerous hazards that have been identified with toys. CPSC incorporated this industry consensus standard into a mandatory standard for toys (16 CFR part 1250).

For electrically operated toys or other electrically operated articles intended for use by children, the requirements are set forth in 16 CFR part 1505. This covers any toy, game, or other article designed, labeled, advertised, or otherwise intended for use by children which is intended to be powered by electrical current from nominal 120 volt branch circuits

For CB Antennas, requirements are set forth in 16 CFR part 1204 - Safety Standard for Omnidirectional Citizens Band Base Station Antennas.

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Short of creating a technical regulation, CPSC can recall products, or prevent importation of products, if they fail to meet critical safety requirements from a certain specific industry consensus standard.

Section 15(j) of the CPSA provides authority to specify for any consumer product or class of consumer products, characteristics whose existence or absence are deemed a substantial product hazard under section 15(a)(2) of the CPSA.

A product within the scope of section 15(j) must have specific, observable, product characteristics that are required by an industry consensus safety standard.

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The Commission has determined that products that do not comply with a 15(j) regulated requirement present a defect and are a substantial product hazard.

Therefore, products that do not comply with an applicable 15(j) requirement cannot be imported into or sold within the United States.

Handheld Hair Dryers, Holiday Lights, and Extension Cords are electrical products subject to 15(j) regulated requirements.

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Household and commercial handheld hair dryers must have an integral immersion protection circuit interrupter plug (as per UL 859 and UL 1727) as specified under 16 CFR § 1120.3(a). The photo shows two examples of an immersion protection plug.

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Seasonal and decorative lighting products must meet the minimum wire size requirements of UL 588, have sufficient strain relief, and include integral overcurrent protection, as specified in UL 588. The requirements under 15(j) for holiday lights are codified under 16 CFR § 1120.3(c). The photos show examples of decorative lighting products and a light string.

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Seasonal and decorative lighting products that are not within the 15(j) requirements scope include Class 2 power products, solar-powered products and rope lights/luminaires. The photos show examples of out-of-scope products, from left to right, a class 2 power adapter, a USB-powered decorative lighting product, a solar/battery-powered light string and a rope light.

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Extension Cords must meet the minimum wire size requirements, have sufficient strain relief, and be properly polarized. Indoor-use cords must have outlet covers while outdoor-use cords must be jacketed. All requirements are specified in UL 817, as codified in CPSC's regulations under 16 CFR § 1120.3(d). The photos are examples of indoor and outdoor extension cords.

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Power cords that are not under the scope of the 15(j) requirement include detachable power supply cords, relocatable power taps and appliance cords, examples that are shown in the photos.

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Electrical products not subject to a regulation do not require certification by an accredited third party lab (e.g., UL, Intertek or CSA) to an industry consensus standard, but staff observes a high rate of 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 by a Nationally Recognized Testing Laboratory (NRTL) for electrical products used in a workplace.

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

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

CPSC statutes assign the responsibility for safe products to all parts of the supply chain, namely manufacturers, importers, distributors and retailers.

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Manufacturers and importers should follow best practices to ensure that their electrical products do not pose unreasonable risks of injury. This includes assuring products comply with consensus standards and technical regulations, obtaining certification from an accredited lab to assure and demonstrate products meet applicable industry consensus standards, maintaining quality and configuration control throughout the production life cycle and, similarly, assessing impacts of material or component substitutions during the production life cycle.

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With such a heavy reliance on industry consensus standards, staff is engaged in maintaining the adequacy of industry consensus safety standards, including addressing emerging hazards, by actively participating through development and proposal of new or modified requirements.

This is an ongoing process that can be described by five steps, which begins with staff gathering incident information from CPSC's data collection systems. Next, staff analyzes the data for hazard patterns, reviews applicable standards for inadequacies in addressing the defined hazard patterns, conduct tests and evaluations to support findings as needed, proposes standards development or revisions to existing standards, and participates in industry consensus standards committees to support the recommendations . . . hopefully culminating in an approved revision.

One example of this is UL 2272 – standard for safety for Electrical Systems for Personal E-Mobility Devices, which staffed helped develop in 2016 to address hoverboard overheating incidents.

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CPSC staff relies on incident data to help guide efforts toward the most serious risks. Staff learns about product-related incidents from many sources and maintains incident data in five databases: the Injury and Potential Injury Incident Database or IPII, the Death Certificate database or DTHS, the In-depth Investigation database or INDP, the National Electronic Injury Surveillance System, or NEISS, and the National Fire Incident Reporting System or NFIRS, which is actually operated by the US Fire Administration.

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The IPII database includes information from the Medical Examiner and Coroner Alert Program, News Clips, hotline calls, internet reports, compliance reports, federal and state agency referrals, other sources. IPII provides anecdotal accounts of product-related incidents.

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The DTHS database is a staff-maintained collection of death certificates received through contracts with the 50 states. The agency purchases approximately 8,000 death certificates per year. A time lag can occur between the date of the fatal incident and the entry date into the DTHS system. Epidemiological staff reviews new death certificates daily. Death certificates provide specific details on death-related incidents caused by products, but typically provides minimal product details.

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The INDP database is a collection of CPSC field staff reports on follow-up investigations to initial incident reports. Investigations can occur on site, meaning in person, or by telephone. Investigations include collaboration with local officials, such as medical examiners, police, and fire departments. Field staff may also collect incident or exemplar samples for examination by technical staff. INDP provides specific details on a product and its involvement in an incident.

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NEISS data are collected from a sample of approximately 100 hospital emergency rooms around the country. Hospitals collect data on incidents associated with consumer products. Coders at each hospital submit their incident data each day. The data are weighted to provide consumer injury estimates nationwide. CPSC collects about 395,000 consumer product-related injury reports annually through NEISS. Data are available from 1980 to present. NEISS provides statistically significant data with details on product-related injuries, but provides less detail on specific products than some of the other data sources.

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This map shows the distribution of participating hospitals and their relative sizes across the United States.

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The NEISS system includes 14 variables that provide significant detail on the victims and the type and severity of injury

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NEISS data are available to the public and can be queried by date spans, products, gender, age, disposition, body parts, and diagnosis from the CPSC website:
<https://www.cpsc.gov/cgibin/NEISSQuery/home.aspx>

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NFIRS is a collection of voluntarily reported fire incidents input by the attending fire service.

This is not a statistical sample, but staff uses these data in conjunction with the National Fire Protection Association's annual national fire survey to develop annual estimates of fires and their causes. Here is a link to the 2020 staff report of fire loss estimates

https://www.cpsc.gov/s3fs-public/2015to2017ResidentialFireLossEstimates.pdf?lrPHs2JTqq5ijz9zvLHL3zfukzWUKw_X

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Since 2016, staff has been engaged in a project to address hazards associated with high-energy density batteries in consumer products.

Efforts include industry consensus standards work, import surveillance and compliance, and industry, interagency, and intergovernmental cooperation. Staff issued two status reports on the project:

Status Report on High-Energy Density Batteries Project

February 12, 2018 - https://www.cpsc.gov/s3fs-public/High_Energy_Density_Batteries_Status_Report_2_12_18.pdf?UksG80UJqGY0q4pfVBkbCuUQ5sNHqtW0

FY 2020 Status Report and Action Plan for the High-Energy Density Batteries Project March 2020 - https://www.cpsc.gov/s3fs-public/High%20Energy%20Density%20Batteries_Status%20Memo_FY20_1-6bCleared-04012020.pdf?Qj4t_otWKfBZYLpvu4l6sUvx9ZJfFc4f

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Also, staff sponsored the Naval Surface Warfare Center Carderock Division to conduct a study on lithium battery technology and an evaluation of mitigation techniques for multicell battery pack failures, issuing the following reports:

Emerging Energy Storage Technologies October 2020 - https://www.cpsc.gov/s3fs-public/NSWCCD-63-TR-2020-39_Emerging-Energy-Storage-Technologies_DIS_A_VERSION_ForPostingVersion12012020.pdf?wYqrWGAzQLL53BlqSYr8RfCwb2eiznIT

Evaluation of Cell-to-Cell Propagation in Lithium-Ion Batteries Containing 18650 Sized Cells January 2020 - https://www.cpsc.gov/s3fs-public/Consumer%20Product%20Safety%20Commission%20%28CPSC%29%20Staff's%20Statement%20on%20Naval%20Surface%20Warfare%20Center%2C%20Carderock%20Division's%20%28NSWCCD%29%20Report%20on%20%Evaluation%20of%20Cell-to-Cell%20Propagation%20in%20Lithium-Ion%20Batteries%20Containing%2018650%20Sized%20Cells%.pdf?KKybsoSCNBqeX46SxJbUq2NgkkzZk_Wd

Staff is continuing to evaluate means of mitigating multicell battery pack failures and is participating in a cooperative effort with Canadian and Mexican governments to evaluate power banks.

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From FY 2017 to FY 2020, there were 32 recalls associated with batteries involving 15 types of consumer products totaling nearly 1.75 M units.

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The top four products by number of units recalled from FY 2017 to FY 2020 were a laptop, two power banks, and a wireless speaker.

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Some of the causes of root causes of battery product recalls include quality control problems in cell manufacturing, such as improper placement of leads, contaminants in cell, uneven forming of cell, poor quality welds, insufficient electrode overlap, physical damage to cell, and missing insulating tape on terminal tabs.

Battery pack design problems include: no safety circuits, inadequate (or any) overcharge/over-discharge protection, and inadequate physical protection.

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One example of a root cause of lithium-ion battery recalls that we'll cover is cell contamination in a third party certified 18650 cell used in a laptop battery pack. Laptop overheating incidents revealed defective cells. Cells examined by the manufacturer revealed metallic particles (iron) adhered to an electrode. Metallic particles can perforate separator and short electrodes. Cells can overheat, possibly going into thermal runaway.

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Additional investigation by the manufacturer revealed a manufacturing error occurred when an electrode-cutting chuck was repositioned improperly to keep a production run operating - interference occurred, creating iron particles.

The manufacturer took several corrective actions including re-aligning the chuck by the next shift and tracking assembly line production from affected dates, both of which limited the scope of recalled products. Subsequently they implemented a process to control further issues with chuck alignment and reviewed and reduced other metal-to-metal processes in cell manufacturing.

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Some general cell contamination mitigation actions include magnets to capture loose ferrous particles, suction 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, and computed tomography x-ray scanner for a more detailed non-destructive inspection.

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Another example of a root cause that necessitated a recall is physical damage from poor handling techniques at the factory. These cells were not certified. Rough handling damaged the outer foil of a polymer cell, which could result in internal soft shorts. The photos show tears in the foil of two cells. In order to correct these types of issues, the manufacturer instituted improved handling and storage procedures and enhanced worker training. Also, the manufacturer added an extra visual inspection before batteries leave the factory.

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A third example of a root cause that necessitated a recall is a manufacturing assembly error - Insufficient electrode overlap. The photos show x-rays of a cylindrical cell that has inconsistent electrode overlap. Inadequate overlap may result in lithium plating at the edges, which may eventually become short circuits. IEEE 1625 - *Standard for Rechargeable Batteries for Multi-Cell Computing* and IEEE 1725 - *Standard for Rechargeable Batteries for Mobile Telephones* prescribe that the negative electrode shall be at least 100 μm wider (plus process margin) than the positive electrode on top and bottom of the cell.

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As indicated previously, x-ray examination is useful for both manufacturing inspection and failure analysis. The photo on the left is of a pair of 18650 cells from a hoverboard, the photos on the right are images from CPSC's CT x-ray machine, showing clear views of the damage to the cell without destroying the sample.

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While nondestructive testing is beneficial, particularly at the beginning of an assessment, dissection and visual examination may be necessary. These images depict a dissected cell from a cellular phone to assess the height of the welds on the tabs. Excessive amplitude on ultrasonic welds can produce high peaks that could penetrate separator and cause shorts.

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The next sequence of slides will be a case study on how products without a standard can develop problems when best practices are not followed. In late 2015, hoverboards flooded the US market. These units were powered by a rechargeable lithium-ion multi-cell battery pack; there was no existing industry consensus standard for the end product.

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Almost immediately, incidents were occurring – fires and falls.

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From November 2015 to May 2017, CPSC staff logged more than 165 fire incidents, causing over \$3M in property damages. Incidents occurred in 38 states. They occurred during and after charging and during and after riding. There were two deaths in one fire incident.

NEISS data showed an estimated over 10,000 Emergency Room Visits, ~90 percent from falls, *e.g.*, sudden stops and starts. There was one death. There were approximately ~15 percent head injuries, ~50 percent arm injuries, ~40 percent fractures, and ~30 percent sprain/abrasions.

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At the end of 2015, and into 2016, CPSC staff conducted assessments of hoverboards. Staff examined incident units and tested exemplar units on a dynamometer and with riders. We found that fire incident units exhibited signs of thermal runaway leading to catastrophic failure of the entire battery pack. Units were largely similar in construction with 20 Type 18650 cylindrical lithium-ion cells in a 10S-2P (10 pairs of parallel-connected cells in series) configuration.

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Staff also observed that battery management system (BMS) circuits did not incorporate thermal sensing to prevent cell charge/discharge outside of temperature specifications. In these two photos, the red circles show an area on the circuit board where a thermal sensor could be connected but were not.

Internal wiring was not installed in accordance with standard practices to protect against damage/shorting: There were loose wires not bundled/secured, wires that were routed through openings in cast metal that was not deburred, and wiring that was not sheathed where passing through the pivot.

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Rider tests revealed peak battery currents over 20 A as shown in the upper right graph. Dynamometer tests showed battery case temperatures well above typical operating temperatures, as shown in the lower graph.

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From their assessments, staff came to the following findings: The units had failed protective circuit analyses and thus had inadequate BMSs. The cells (and pack) were inadequate for the system load requirements. The cells were not certified to UL 1642 to ensure cells are manufactured in accordance with the standards. Many of the battery chargers were not certified to a standard (UL 1310, UL 1012, or UL 60950-1). The wiring in the base was not properly secured or protected in the base pivot, so it was subject to physical damage and shorting.

From this staff concluded that the units posed a risk of fire, and over 500,000 units were recalled.

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Over the next few slides, we will show that even products designed and constructed under well-established standards and with high rates of third party certification can pose risks of fire when best practices are not closely followed. These photos show examples of a cellular telephone and a laptop that both exhibited battery failures that went to fire. Earlier we reviewed a laptop that had been recalled due to contaminants in cells, now we'll look at a

cellular telephone that had its original cell and replacement cell experience different manufacturing errors that resulted in thermal failures.

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Despite adherence to industry consensus standards and the batteries and phones being certified, manufacturing errors occurred from two different cell manufacturers. For the first manufacturer (A), post-incident analysis revealed that the incident failures were likely caused by damage to the negative electrode at the corner of pouch. There was inadequate volume in the pouch to accommodate the electrode assembly. The damage could result in lithium plating or separator damage, either of which could cause shorting and eventual thermal runaway of the cell. The phones with the Manufacturer A battery were recalled and replaced with models incorporating Manufacturer B batteries. The replacement battery had sufficient pouch volume for the electrode assembly.

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After the replacement phone was in use, additional thermal incidents occurred. Subsequent analysis of incident samples revealed that short circuits had initiated at the positive electrode tab weld. Further analysis by the firm indicated that the shorts were caused by either defective welds and missing insulating tape over the tab weld that would provide further protection from shorts from weld defects.

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Consequently, the cell phone manufacturer reviewed its internal procedures to tighten its manufacturing controls to assure that it could detect problems. These included X-ray inspection of all cells to check battery corners; voltage decay measurement procedures to identify cells with potential problems; increased sampling, cycling, dissection and examination of cycled cells; additional flexing tests of the phones and proposed a review and upgrade of IEEE 1725.

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Over this final sequence of slides, we will review the best practices for manufacturing lithium-ion and lithium polymer cells and products that include these cells. Of course, it starts with the cell. There are various electrode chemistries (LCO or lithium cobalt oxide, LMO or lithium manganese oxide, NMC or lithium nickel manganese cobalt, and LFP or lithium iron phosphate) that have different performance specs and varying levels of safety. It's important to be aware of the differences and make sure it's the best one for the application.

Cells contain flammable electrolytes - defective or abused cells can enter thermal runaway condition, producing extreme heat and energetic disassembly.

Critical safety circuits to control voltage, current, and temperature during charge and discharge keep cells within their safe operating area.

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Be certain to maintain cells within their specified safety region during charging and discharging, as these graphs from the Japan Electronics and Information Technology Industries Association and Battery Association of Japan illustrate.

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Some more specific guidance for charging is to disable charging if cell surface temperatures are exceeded. Also at the beginning of a charge cycle, if a cell is below 3 V, charging should be disabled or pre-charge charging rate should be used. At the end of the charge cycle, when charge current drops to .05C, the charger should be disabled so that the cell is not trickle charged. The graph on the right illustrates the charging stages for typical lithium-ion cells.

Additional keys are to maintain the balance of cells in multicell packs and to assure that the charger is compatible with the cells/battery for all of these conditions.

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It is also critical to properly monitor and maintain cell temperatures below maximum operating limits for all modes of operation. This can be accomplished by use thermal sensors (red circles in photos) that are properly placed and affixed and/or use of thermal insulators (green arrows in photos) to avoid excess temperatures.

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In addition to safety circuit protection such as from a BMS, integral cell protection can provide redundant protection against abuse conditions. This includes a current interrupt devices (CID), which disconnects the cell from its terminal under excessive internal pressure and a resettable Positive Temperature Coefficient (PTC) device that changes resistance and limits current. PTC current limiters may not be suitable for high-drain applications and do not protect against thermal runaway due to internal faults

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If an application requires that a cell be user replaceable, the cell should have integral protection, including an integral BMS to provide charge control and to protect against over-charge, over-discharge and external short-circuit.

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CPSC technical staff recognizes that Lithium-ion battery safety requires diligence from producer to user.

Lithium-ion battery products should be designed and built in accordance with applicable industry consensus standards using high quality cells, suitable for the application. During all operating modes, cells should be maintained with manufacturer's specifications, especially for

voltage, current, and temperature. The system from charger to cell should be evaluated together for complete compatibility.

Cells and battery-powered end products should be manufactured in strict accordance with industry standard quality control processes. This is for the entire production cycle, being certain to maintain configuration control with only approved material or component substitutions, subjected to impact assessments

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Lithium-ion battery products should be properly marked with warning labels to inform/educate users of the potential hazards and to closely follow manufacturer's instructions for proper use. CPSC staff recommends that cells and battery-powered end products be third party certified by an accredited laboratory.

Finally, under CPSC's statutes, manufacturers, importers, distributors and retailers are responsible to assure consumer products to do not present an unreasonable risk of injury or death and ensuring these best practices are followed are critical to that goal.

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Thank you, and we hope you enjoyed this podcast. If you have any questions on the presentation, please do not hesitate to submit your questions in English or Chinese to the mailbox mentioned earlier: CPSCinChina@cpsc.gov. This mailbox is routinely monitored.

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We also wish to remind viewers that CPSC has many technical documents and resources available in Chinese. At the conclusion of this presentation, we provide many links to resources viewers may find useful.

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We encourage viewers to be sure to check out CPSC's Regulatory Robot, available in English, Chinese, and several other languages. The Regulatory Robot is an automated tool that can help identify safety requirements for many different types of products. Many companies have found this tool to be extremely helpful.

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Please also see the following slides to view a variety of battery specific resources.

Thank you for downloading this presentation.