Lithium Battery Safety: Good Batteries Gone Bad

A Joint Service Presentation and Discussion by

Clint Winchester
Carderock Division
Naval Surface Warfare Center

Dave Kiernan
Directorate for Safety
US Army CECOM

Joint Service Power Expo

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Background

- This presentation is unclassified
- Portions of this presentation are intended to illustrate the potential dangers associated with using high energy power sources
- Some of the images shown are the extreme results of aggressive and deliberate battery abuses
- Some of the events described are examples of things that can (and have) occurred during routine activities

Outline of Presentation

- Overview of Battery Safety Resources within the Services
- Overview and Discussion of Battery Hazards
- Overview of the Navy's Lithium Battery Safety Approval Process
- Overview of the Army's Lithium Battery Safety Policy
- The Basics of Lithium Battery Safety Testing
- Videos of High Energy Battery Tests
- Questions

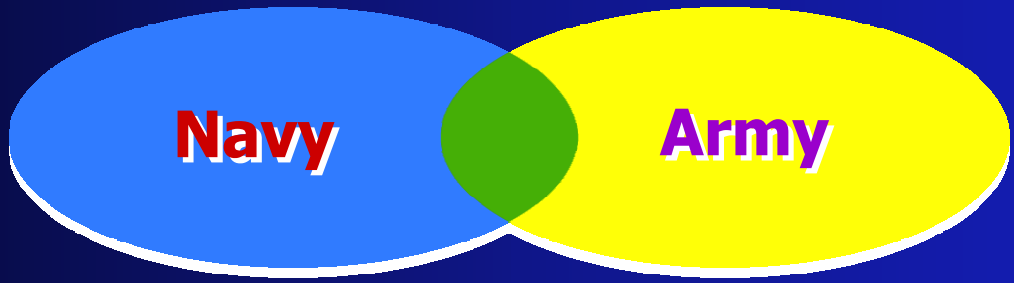
Battery Safety Resources within the Services

- **NAVSEA Power Systems Team**
  - Naval Surface Warfare Center, Carderock Division
    POC: Clint Winchester (301) 227-1853
    winchestercs@nswccd.navy.mil
  - Naval Surface Warfare Center, Crane Division
- **CECOM Directorate for Safety**
  POC: Dave Kiernan (732) 427-7469
  David.Kiernan@us.army.mil
- **USMC PM Expeditionary Power**
  POC: Joanne Martin (703)
  joanne.martin@usmc.mil

How Power Systems Overlap Among the Services

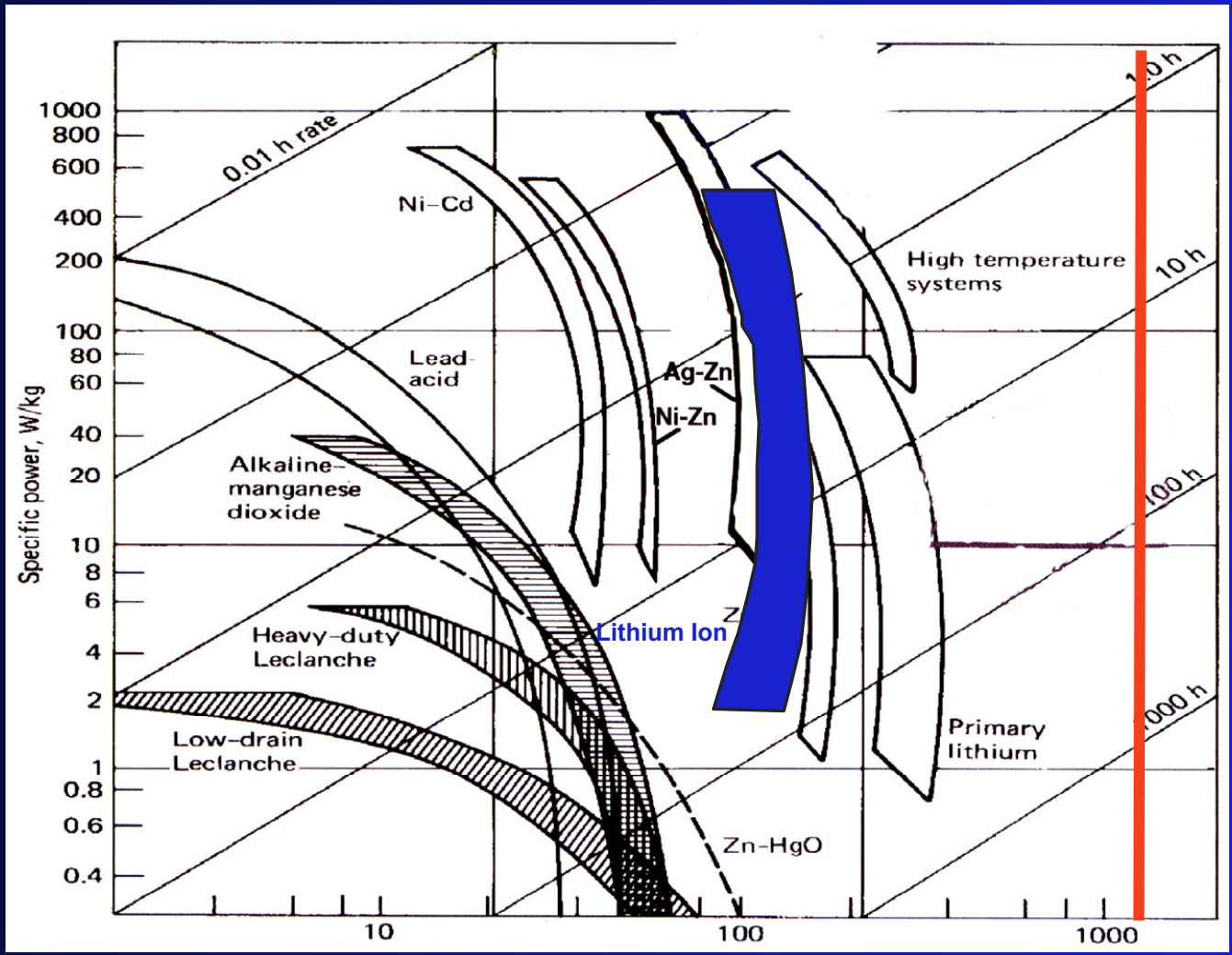
Army equipment used by Marines aboard Naval platforms…

How Power Systems Overlap Among the Services



Naval Applications w/Lithium Batteries	USMC	Army Applications w/Lithium Batteries
Missile Systems	Communication Equipment (SINCGARS)	Communication Equipment (SINCGARS)
Mines	Emergency Radios (CSEL)	Emergency Radios (CSEL)
Torpedos	Battlefield Planning Devices (AN/PSC-2)	Battlefield Planning Devices (AN/PSC-2)
Countermeasure UUVs	Night Vision Goggles	GPS (AN/PSN-11, PLGR)
Air and Sea Targets		Missile Guidance and Control
Sonobuoys		Night Vision Goggles

Delivered Power and Energy Comparisons



1375 Wh/kg = TNT

Lithium Batteries Used by the Military

- **Battery Types**
  - Primary
    - Active
    - Reserve
      - Liquid Reserve
      - Thermal
  - Secondary
- **Cell Designs**
  - Bobbin
  - Spiral
  - Bipolar
  - Coin
  - Prismatic
- **Battery Chemistries**
  - Cathode
    - Manganese Dioxide
    - Carbon Monofluoride
    - Thionyl Chloride
    - Sulfur Dioxide
    - Sulfuryl Chloride
    - Vanadium Pentoxide
    - Cobalt Oxide
  - Anode
    - Lithium Metal
    - Lithium Alloy
    - Lithium Ion
  - Electrolyte
    - Organic Liquid
    - Polymer/Gel
- **Cell Sizes**
  - Button Cell (0.01 Ah)
  - AA-Size Cell (2 Ah)
  - D-Size Cell (10-20 Ah)
  - Specialty Design Cell (2,200 Ah)
  - Air Force Design Cell (10,000 Ah)

Battery = Stored Chemical Energy

- Controlled Release of This Energy Provides Electrical Power in the Form of Current and Voltage
- Uncontrolled Release of This Energy can Result in Venting, Fire, Release of Toxic Materials, Shrapnel, High Pressure Events, Deflagration (with or without Report) and Many Combinations Thereof

Battery Hazards

- **Explosion**
  - Unintentional charging by end item
- **Venting, possibly under high pressures**
- **Release of hazardous materials**
  - Noxious, toxic or hazardous gases
  - Strong acids or bases (liquid or gas)
  - Flammable gases and liquids
- **Fire**

Venting

- **A normal venting is the controlled release of cell's electrolyte through its venting mechanism**
- **Cell defects or abuse may result in ventings that may be high pressure events producing shrapnel**
- **Release of internal pressure from a cell by ejecting some or all of its internal components into the environment**
  - These components may be flammable and may include noxious gasses
    - Li/SO_2 battery releases acutely toxic and flammable gases
    - Li/MnO_2 battery releases flammable gases
  - A venting of a lithium ion battery may release
    - Flammable organic electrolyte (e.g. PC-EC-DMC)
    - $LiPF_6$ -- this material is reactive with water; forms HF acid
    - Carbon either as carbon or water reactive lithiated graphites
    - $LiNiCoO_2$ or other lithiated oxides and heavy/transition metals
    - Metal foils and fragments (copper or aluminum)
    - Methane, hydrogen, carbon monoxide (electrolyte decomposition products)
- **Ventings may be accompanied by smoke, sparks and or flames**

Violent Venting of a Lithium Ion Battery

Various Lithium Primary Battery Abuse Responses

Likely Mistreatment Scenarios

- **Physical abuse, such as crushing, puncturing or burning**
- **Overcharging due to electronics failure**
- **Charging of primary (non-rechargeable) batteries**
- **Exposure of battery to inappropriate environment**
  - High temperature abuse (140°C)
  - Water immersion of an unprotected or unsealed battery
- **Short circuit or abnormally high rate discharge of battery**
- **Improper use of or incorrect batteries used in an end item**

Some Results of Mistreatment

Typical Battery Responses

- **Battery responses to abusive conditions vary depending on:**
  - Chemistry
  - Size (cell and battery)
  - Protective devices and circuitry
  - System characteristics
    - Thermal management
    - Battery container free volume and seal method

General Response Trends

- **Li/SO_2 primary batteries**
  - May vent mildly in response to a variety of conditions including age, short circuits, overdischarge, and high temperature exposure
  - May vent violently due to manufacturing defects
  - May explode when charged at moderate to high current rates to greater than 100% capacity
- **Li/MnO_2 primary batteries**
  - May vent with flame in response to moderate to high rate discharge into voltage reversal
  - Severity depends on both abuse conditions (rate and duration) and chemical composition of the battery
- **Li Ion rechargeable batteries**
  - May vent with flame in response to overcharge conditions
  - Severity depends strongly on combination of current rate, over-voltage and duration

Overview of Navy's Lithium Battery Safety Review Process

- **Program office requests safety review IAW Navy Lithium Battery Safety Program requirements**
- **NSWC Carderock conducts lithium battery safety evaluation**
  - Compile and/or review data package describing battery design, system design, deployment and use scenarios
  - Conduct safety testing IAW Navy Lithium Battery Safety Program requirements for new or unique batteries or battery/system combinations
  - Analyze all available data to conduct hazard assessment and risk analysis for use use of the battery
  - Make recommendation for or against use, or for design changes
- **Naval Ordnance Safety and Security Activity (NOSSA) issues final determination letter**

Documentation for the Navy's Lithium Battery Safety Program

- **Instruction -- Defines the Process**
  - NAVSEAINST 9310 Initial Release in 1979
  - NAVSEAINST 9310.1a of 11 March 1982
  - NAVSEANOTE 9310 of 11 June 1985
  - NAVSEAINST 9310.1b of 13 June 1991
  - NAVSEAINST 9310.1c in Preparation
- **Technical Manual -- Guidelines for Design, Review and Procedures for Testing**
  - Technical Manual for Batteries, Navy Lithium Safety Program and Procedures S9310-AQ-SAF-010 of 19 Aug 2004

Overview of Army's Lithium Battery Safety Policy

- **Validation of safety of lithium batteries is an integral part of the Acquisition Requirements**
- **Manufacturers perform tests and assess the safety of their batteries as required by their battery procurement contracts**
  - Tests verify the performance of safety devices
- **Army performs independent tests on each manufacturing lot**
- **Once a battery design has been deemed "safe for use" it is frozen, and cannot be changed without approval of the government**
- **Batteries are deemed "safe for use" independently of the system that they are used in**

Documentation for Army's Lithium Battery Safety Policy

- MIL-PRF-49471 for Non-Rechargeable Batteries
- MIL-PRF-32052 for Sealed, Rechargeable Batteries
- UL 1642, Standards for Lithium Batteries
- UN ST/SG/AC.10/27/add.2, Recommendations on the Transport of Dangerous Goods, Manual of Test and Criteria

The Multi-Service Approach to Lithium Battery Safety Approval

- **In the past, fully developed Army batteries were later subjected independently to the Navy's safety requirements**
  - BA-5590/U
  - BA-5800/U
  - BB-2847/U
- **In some cases, a joint battery certification approach has been developed in parallel with system design**
  - CSEL
- **Recently, qualification test data and test samples of new Army batteries have been provided to the Navy for parallel safety evaluation IAW Navy requirements**
  - BB-2590/U
  - BA-5390/U
- **In the future, the Army plans to procure to a specification that includes Navy safety requirements for additional safety tests**

Primary Lithium Battery Safety Tests

- **Per Navy/USMC Requirements**
  - Electrical Safety Device Test
  - Forced Discharge into Voltage Reversal Test
  - Short Circuit Test
  - Charging Test
  - High Temperature Abuse Test
- **Per Army Performance Specification Requirements**
  - Short Circuit
  - Forced Discharge
  - Overload and High Temperature Overload
  - Abuse Test with Predischarge
  - Abuse Test with Overload and Pulsed Discharge
  - Mechanical and Thermal Shock
  - Drop
  - Vibration
  - Immersion
  - Altitude

Rechargeable Lithium Battery Safety Tests

- **Per Navy/USMC Requirements**
  - Electrical Safety Device Test
  - Overcharge Test
  - Overdischarge Test
  - Short Circuit Test
  - High Temperature Abuse Test
- **Per Army Performance Specification Requirements**
  - Electrical Safety Device test including over temperature cut-offs
  - Overcharge and discharge and short circuit testing
  - Environmental testing – Shock, Drop, vibration, and immersion
  - UN transportation testing

Let's Go to the Tapes…

Conclusions

- Batteries come with a variety of different characteristics, and these should be carefully matched to the requirements of a given application
- Within the group known as lithium batteries, there are a wide variety of specific characteristics
- Specific battery hazards depend on both battery and system-related variables
- The primary function of the Army's and Navy's Lithium Battery Safety Programs is to minimize risk to personnel and platforms while allowing the use of lithium batteries to advance our military capabilities
- The Army, USMC and Navy have made great strides in coordinating joint program needs to concurrently evaluate and safety certify cross-service lithium and lithium-ion batteries