Naval Surface Warfare Center, Carderock Division

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Safety Testing of Lithium-Ion Batteries for Military Applications

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Presented at the Workshop on Decarbonization of Rail Transportation on 5/16/23

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Background and Outline

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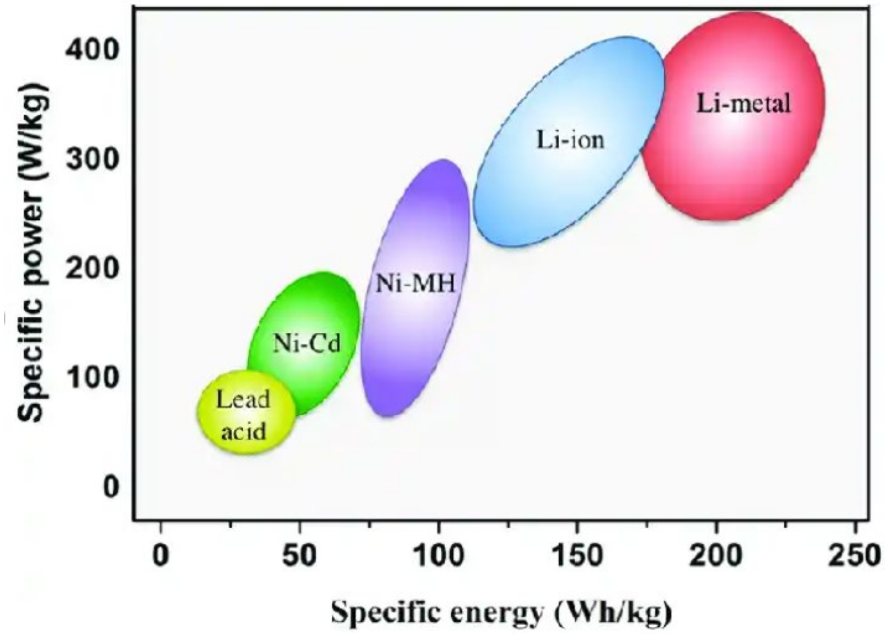
- Information included in this presentation is unclassified
- The purpose of this presentation is to provide information about the Department of the Navy's (DoN) Lithium Battery Safety Program (LBSP)
- Some of the images shown in this presentation are the extreme results of aggressive and deliberate battery abuses

Lithium Batteries in the News…

Advantages of Lithium Batteries

- Excellent cycle and calendar life
- Lower self discharge rate
- Low maintenance
- No out gassing
- Energy density (volumetric and gravimetric)
- Improved reliability
- Improved performance
- Extended mission durations



Lithium Battery Casualty Types

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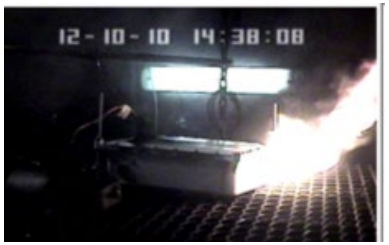
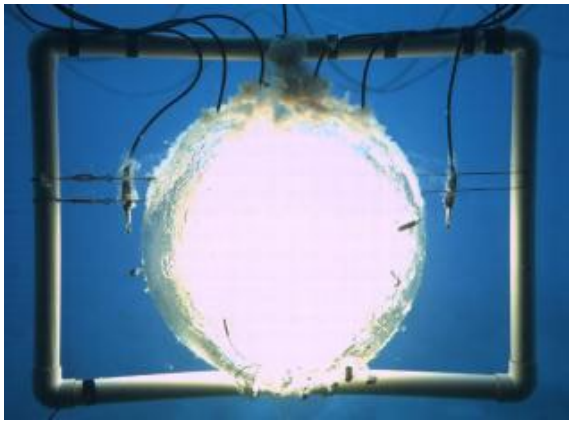
Venting

- Release of internal pressure from a cell by ejecting some or all of its internal components into the environment
- Components may be flammable
- Components may include noxious gasses
- Cell ventings may be benign with all components contained within the next level assembly
  - Battery housing
  - System housing
- Ventings may be accompanied by smoke, sparks and or flames
- Ventings may be high pressure events



Thermal Runaway

- Occurs inside of lithium cells when conditions reach the “point of no return”
- Thermal runaway refers to a situation where an increase in temperature changes the conditions in a way that causes a further increase in temperature, often leading to a destructive result (a kind of uncontrolled positive feedback)
- Can be initiated by electrical or mechanical abuse, or a latent defect that was there from the time of manufacturing



Both lithium and lithium-ion battery failures can result in unwanted, uncontrolled, energy release

Navy's Lithium Battery Safety Program

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Purpose: DoN Lithium Battery Safety Program is to assess, evaluate, and minimize risk to personnel and platforms while allowing the use of lithium batteries on ships, aircraft and submarines

- OPNAV INST 5100.23g Navy Safety and Occupational Health Program Manual assigns authority to NAVSEA for all DoN Lithium Battery Safety
- NAVSEAINST 9310.1c Naval Lithium Battery Safety Program assigns Certification Authority to SYSCOMs with appropriate subject matter expertise
- Technical Publication S9310-AQ-SAF-010 "Navy Lithium Battery Safety Program Responsibilities and Procedures"
  - Provides guidelines for design, describes the safety review process and includes procedures for safety testing
  - Current version is Rev 3 of 3 Nov 2020
  - Rev 4 is drafted and in review now for release by the end of FY23
- Technical Manual SG270-BV-SAF-010 "High-Energy Storage System Safety Manual"
  - Defines additional processes and requirements for all lithium batteries used aboard Navy surface or subsurface platforms, platform hazard analysis
  - Current version is dated 27 Jun 2011
- NAVSEAINST 5100.12M System Safety Engineering Manual invokes MIL-STD-882E for risk assessment, supporting processes outline in LBSP documents
- NAVSEAINST 5000.8 Naval SYSCOM Risk Management Policy gives overarching risk acceptance requirements used to support LBSP process

Battery Safety Testing Requirements per S9310-AQ-010-SAF Rev 3

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- Chapter 13 establishes the minimum safety testing requirements for lithium batteries and lithium battery-powered equipment when used, charged, stored, or transported on Navy facilities, submarines, ships, vessels, and aircraft
- Includes test procedures, test equipment, and pass/fail criteria for lithium battery safety tests
- Specific to battery types
  - Active, non-rechargeable batteries
  - Thermal batteries
  - Liquid reserve batteries
  - Rechargeable batteries
- Testing of a specific battery design is waived when:
  - Results from testing a comparable battery are available and may be leveraged to evaluate by analysis the hazards from the battery design under review (S9310 Rev 3 section 4-1)
  - The battery is non-rechargeable, uses only one type of: 9V or 2/3A-size Li/MnO_2 or AA or AAA-size Li/FeS_2 cells, and less than 25 Wh of electrical energy content (S9310 Rev 3 section 4-2.3)

Battery Safety Testing Requirements per S9310-AQ-010-SAF Rev 3 (continued)

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- Test Unit is defined as “a battery inside a complete system, or a battery inside sufficient system components to simulate the battery/system interactions”
  - In some tests, individual cells, subsections, and/or partially populated batteries may be substituted as test units for large batteries
  - The use of alternative test units and configurations must be justified by the program manager in consultation with the designated NAVSEA Technical Agent
- Pass/fail criteria are provided in S9310, however a "failure" to meet these criteria is not always an automatic block for getting a safety certification; in this case, the test data are evaluated and any residual hazards are reassessed and accepted at by the appropriate risk acceptance authorities
  - Specific to host platform: submarines, aircraft, ships and land
  - Focus on containment of hazards within the envelope of the system as best means of protecting the host platform
  - Test specific passing criteria – battery must not vent in any way in response to the Electrical Safety Device (ESD) test

E.G. S9310 Safety Testing of a Lithium-Ion Rechargeable Battery

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- **Reference S9310 TM sections 13-3.8**
  - Short Circuit Test: overcurrent abuse
  - Overcharge/Discharge Test: overvoltage abuse
  - Overdischarge/Charge Test: undervoltage abuse
  - High Temperature Test: extreme overtemperature abuse
  - Battery Management System (BMS) and Electrical Safety Device (ESD) Test: demonstrates effective performance of safety devices in response to overvoltage and undervoltage
    - High Power BMS and ESD Test (tailored to high power batteries)
  - BMS Short Circuit ESD Test
  - Propagation Test: focuses on inducing a cell-level failure to determine if propagation of the failure is likely to carry to neighboring cells solely on the basis of the output from the trigger cell
  - Additional data requirements to be evaluated during some of the above testing include
    - Heat Release
    - Gas Release

Navy Battery Safety Test Results

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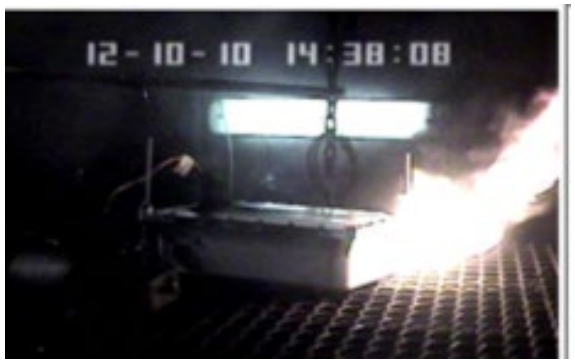
- Battery safety test data provide an assessment tool for determining probability and severity of hazards to personnel, applications and platforms from the specific lithium battery
- Test results characterize battery responses to both likely and unlikely (but more severe) abuse conditions
- Battery-level testing provides a baseline battery characterization that is applicable to the specified system and CONOPs
- System-level testing builds on the baseline data moving to a focus on the shipboard impacts of a high energy lithium battery casualty and verification of the mitigation capabilities of that platform



Conclusions

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- The Navy's Lithium Battery Safety Program strives to minimize risk to personnel and platforms while allowing the use of lithium batteries on our ships, aircraft and submarines to advance our military capabilities through the certification process managed by NAVSEA
- The major classes of hazards associated with most lithium batteries include
  - Venting of noxious and/or hazardous gases
  - Fire
  - High pressure events
- Navy battery safety testing informs risk acceptance
- Specific lithium battery hazards depend on both battery and system-related variables

Technical Agents & Deputy Technical Agents

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- **Technical Agents (TAg) are the stewards of the lithium battery certification process, and operate under formal designated authority from the LBSP Authority. The LBSP Authority has designated NSWC Carderock Division and NSWC Crane Division as the Technical Agents for the LBSP**

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- **Deputy Technical Agents are available to answer questions about the LBSP process and status of ongoing safety evaluations**

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