Lithium Battery Update

Comparison of battery chemistries flammability

Medium Scale Propagation Tests

Over packs

Presented to: Systems Working Group

By: Harry Webster, FAA

Date: November 16, 2011

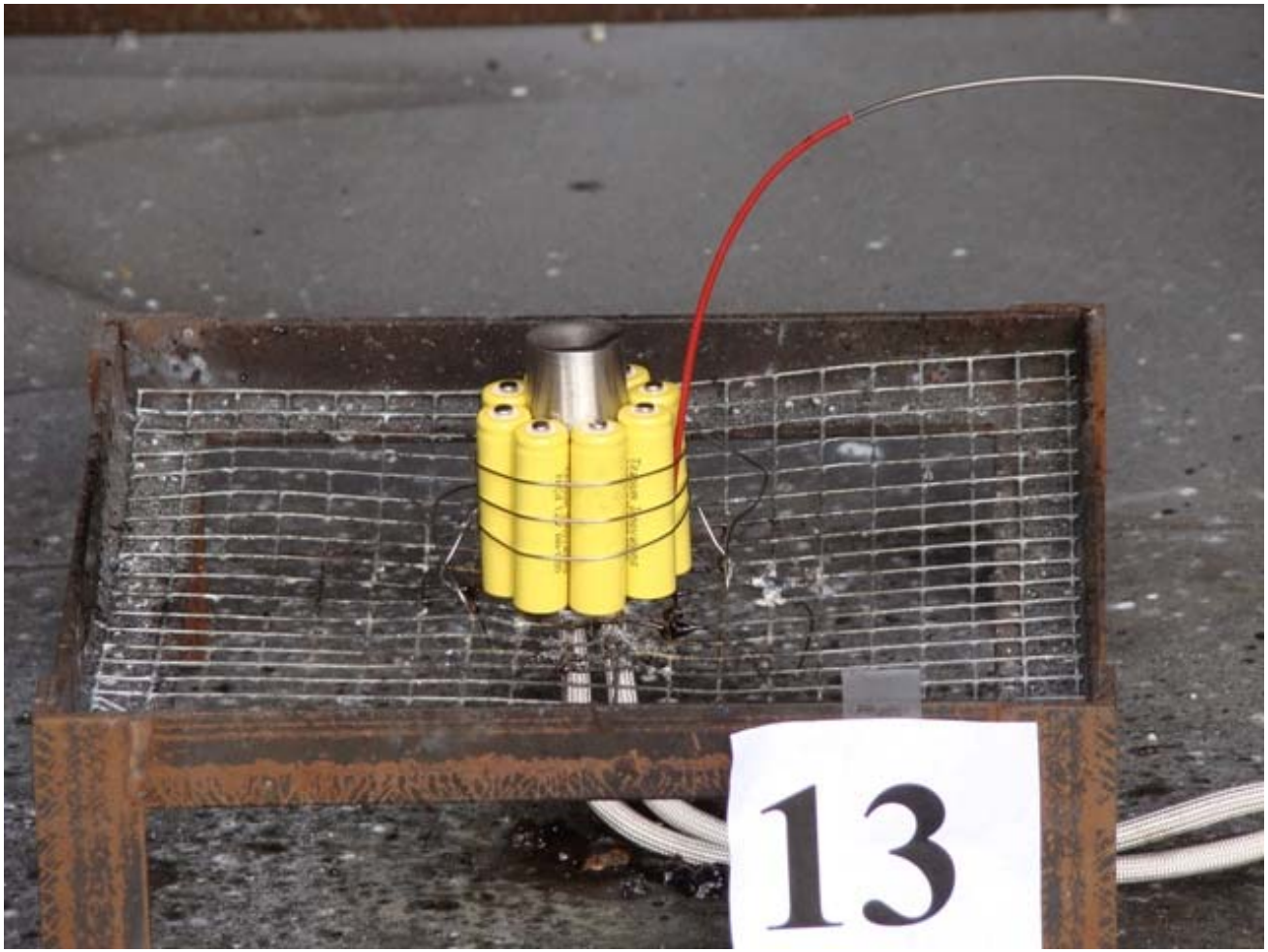
Federal Aviation Administration

Relative Flammability of Various Common Battery Chemistries

- **Tests were conducted using AA size cells**
  - Lithium metal, lithium-ion (3.8 volt), Nickel Cadmium (rechargeable), Nickel Metal Hydride (rechargeable) and common Alkaline.
- **Groups of cells were tested in three modes:**
  - heated using an external alcohol flame
  - heated with a 100 watt cartridge heater
  - Cone calorimeter
    - Heat release at 50 kW/m-2

Alcohol Fire Configuration

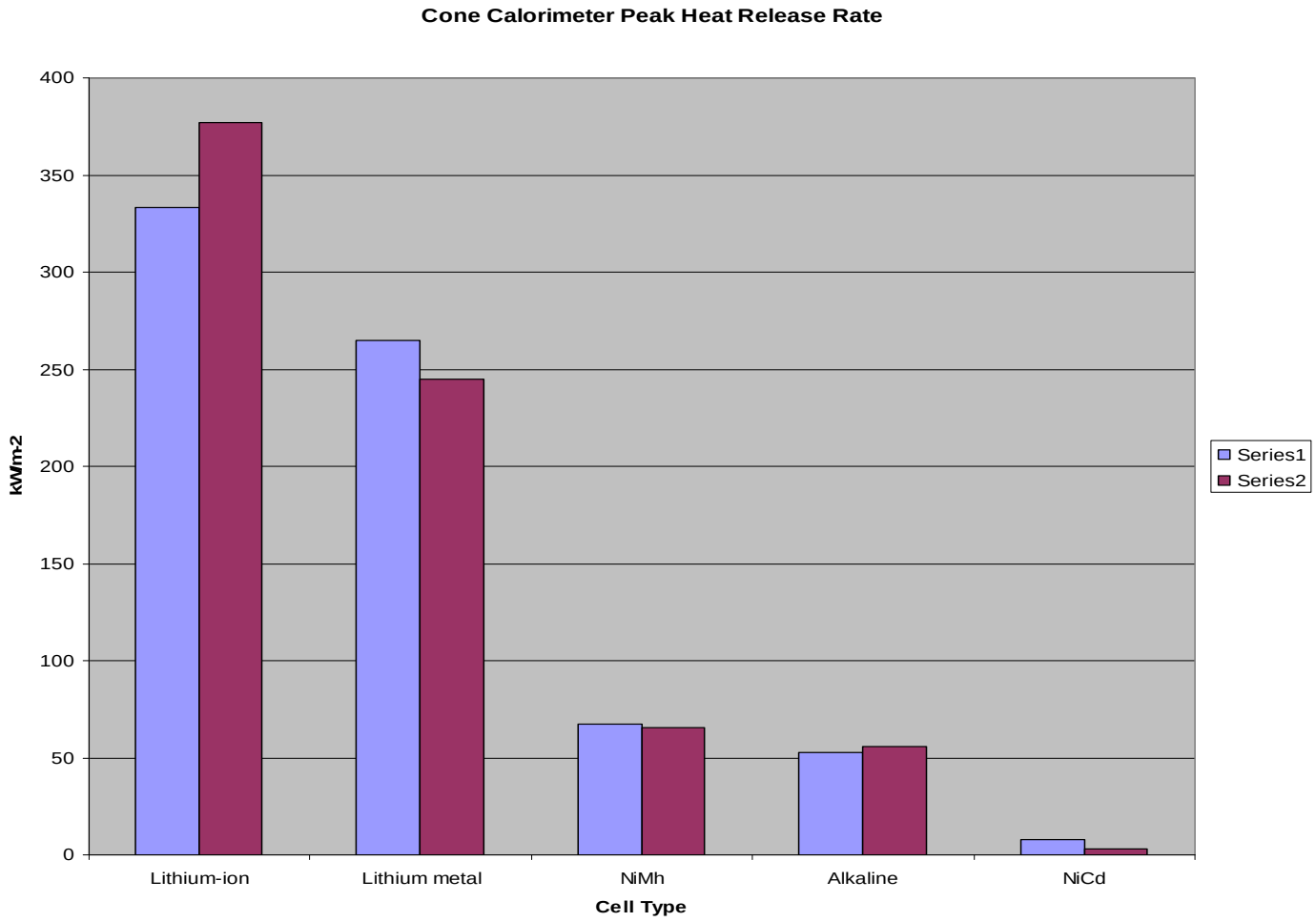
Cartridge Heater Test Configuration



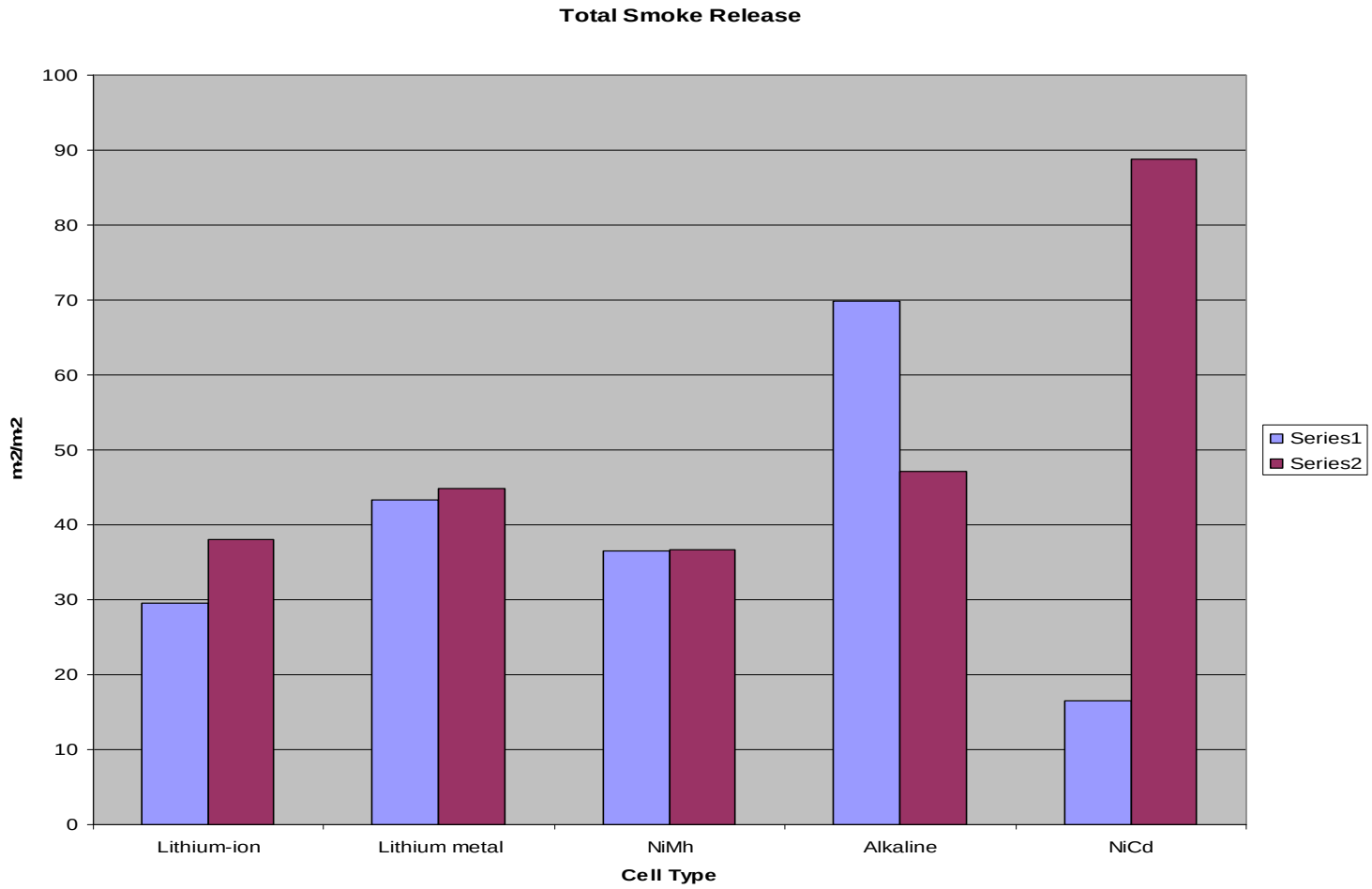
Relative Flammability of Various Common Battery Chemistries

- **Results (in order of risk)**
  - Lithium metal: very strong initial pressure release, highly flammable, molten lithium, flammable electrolyte, pressure pulse
  - Lithium-ion, flammable electrolyte, pressure pulse
  - Nickel Metal Hydride: Pressure release (small), electrolyte somewhat flammable
  - Alkaline: Pressure release (small), non flammable in these tests
  - Nickel Cadmium: non flammable in these tests

Peak Heat Release Rate at 50 kW/m-2



Total Smoke Release at 50 kW/m-2



Relative Flammability of Various Common Battery Chemistries

Small Scale Propagation Tests

- **Tests were designed to measure the propagation of thermal runaway within a shipping package if one cell were to go into thermal runaway**
  - Single box of cells in original packaging
  - One cell replaced with a 100 watt cartridge heater to simulate thermal runaway
  - Thermocouples installed in center and corners of box

Small Scale Propagation Tests Lithium-ion

- **Two tests were conducted, 99 18650 cells**
  - Unsuppressed
  - Halon 1301- 5.5% concentration
- **Results**
  - Unsuppressed
    - Packaging ignited, providing ignition source for venting cells
    - Strong torching fire
    - All cells were consumed
  - Suppressed
    - No open flame
    - All cells thermal runaway
  - Cell temperatures in both tests reached 1100 degF

Small Scale Propagation Tests Lithium-ion Cells

Small Scale Propagation Test Lithium Metal Cells

- **Previous tests have shown that Halon 1301 has no effect on lithium metal cell fires**
- **Single unsuppressed test was conducted**
  - ¼ of standard packaging
  - 115 CR2 cells
- **Results**
  - Initial venting produced open flame
  - Packaging ignited
  - Strong torching fire with white lithium metal sparks
  - Thermal runaway propagated to the entire box
  - All cells consumed within 6 minutes of initial venting

Small Scale Propagation Tests Lithium Metal Cells

Medium Scale Propagation Tests

- **Tests designed to measure the propagation between cells when a single cell fails (thermal runaway)**
  - Lithium-ion and metal
  - Tests with multiple boxes of cells in original shipping packaging
  - Unsuppressed compartments
    - main deck freighter
      - Unlimited ventilation
    - Simulated cargo container
      - Limited ventilation

Medium Scale Propagation Tests Lithium-ion Cells

- **Test conditions:**
  - Unsuppressed compartment, 299 cells, 18650 lithium-ion, three boxes, 100 cells per box
  - Single cell in lower box replaced with 100 watt cartridge heater, simulating thermal runaway
  - Two tests completed
    - Closed test chamber, minimal ventilation
    - Open test chamber, unlimited ventilation

Medium Scale Propagation Tests Lithium-ion Cells

Medium Scale Propagation Tests Lithium-ion Cells

- **Results:**
  - Closed test chamber, limited ventilation
    - Thermal runaway propagated within the lower box
    - Thermal runaway propagated to the upper box, then side box
    - Very little open flame
    - Flash fire near end of test
    - 59 minutes from first venting to flashover
    - 280 cells went into thermal runaway
      - 158 vented as designed, releasing flammable electrolyte
      - 122 exploded, ejecting contents, large pressure release
      - 20 did not vent, retained 3.8 volts

Medium Scale Propagation Tests Lithium-ion Cells

Medium Scale Propagation Tests Lithium-ion Cells

- **Results**
  - Open test chamber, unlimited ventilation
    - Thermal runaway propagated within the lower box
    - Cardboard packaging ignited
    - Thermal runaway propagated to the upper box, then side box
    - No open flame until late in test, 43 minutes from heater activation.
    - Burning fiberboard ignited venting electrolyte
    - 43 minutes from first vent to all flammables consumed
      - 299 cells went into thermal runaway
      - 1 cell unvented, 0 volts
    - No cells exploded

Medium Scale Propagation Tests Lithium-ion

Medium Scale Propagation Tests Lithium-ion

Medium Scale Propagation Tests Lithium Metal

- **Test conditions:**
  - Unsuppressed compartment, 347 123A lithium metal cells, 3 boxes, 116 cells per box.
  - Single cell in center of lower box replaced with 100 watt cartridge heater
  - Single test completed
    - Unlimited ventilation

Medium Scale Propagation Tests Lithium Metal

Medium Scale Propagation Tests Lithium Metal

- **Results**
  - Open test chamber, unlimited ventilation
    - Initial venting produced open flame
    - Lower box fiberboard shipping package ignited and quickly spread to upper box
    - Fire rapidly intensified, spreading to side box
    - All cells consumed within 15 minutes of initial venting
      - 238 cells vented through positive terminal relief ports
      - 89 vented through side of casing
      - 19 exploded
      - 1 unaccounted for

Medium Scale Propagation Tests Lithium Metal

Medium Scale Propagation Tests Lithium Metal

Low Density Propagation Test Lithium-ion Cells

- **Determine the effect of increased spacing between cells on the propagation of thermal runaway**
- **Test Design:**
  - Remove 50% of cells from standard 100 cell 18650 package and arrange so that there is a minimum 0.5” spacing between cells
  - Remove one cell from center and replace with 100 watt cartridge heater.
  - Closed chamber, limited ventilation.

Low Density Propagation Test Lithium-ion Cells

Low Density Propagation Test Lithium-ion Cells

- **Results**
  - Initial venting at 8:13 after heater activation
  - Fiberboard ignited
  - Torching flames
  - All consumables self extinguished at 43:15
  - All cells went into thermal runaway

Low Density Propagation Test Lithium-ion Cells

Oxygen Generator Over Pack Test Lithium Metal Cells

- **Previous tests have shown that the fiberboard/ceramic liner over packs designed for chemical oxygen generator transport are capable of withstanding a lithium-ion cell fire.**
- **A series of tests were conducted to determine the effectiveness of the COG over pack in containing a lithium metal cell fire.**

Oxygen Generator Over Pack Test Lithium Metal Cells

- **Test design:**
  - ¼ of a standard shipping package, 100 123 size lithium metal cells was prepared.
  - The center cell was replaced with a 100 watt heater
  - Thermocouples measured the spread of thermal runaway and the interior temperature of the box
- **Three tests were conducted**
  - Standard taping
  - Wire reinforced taping
  - Wire reinforced taping with vent

Oxygen Generator Over Pack Test Lithium Metal Cells

Oxygen Generator Over Pack Test Lithium Metal Cells

Oxygen Generator Over Pack Test Lithium Metal Cells

Oxygen Generator Over Pack Test Lithium Metal Cells

- **Results: Standard taping**
  - One cell ignited at an elapsed time of 2:30 from heater activation
  - Second cell at 7:50-One lid flap was blown open
  - At 9:00 there was open flame on top of the box
  - By 12:56 all cells were consumed
  - At 16:48 Fire self extinguished
  - Over pack foil liner was perforated, but ceramic not penetrated

Oxygen Generator Over Pack Test Lithium Metal Cells

Oxygen Generator Over Pack Test Lithium Metal Cells

- **Results: Wire reinforced taping**
  - Contained the first two thermal runaways
  - At 10:12 the over pack inflated and the factory stapled seam failed
  - By 11:09, flames escaped from failed seam
  - At 11:37, the exterior of the over pack ignited
  - At 12:42, the over pack was penetrated on the side opposite the failed seam, torching fire
  - 12:52, last audible vent was heard
  - 17:55 over pack and cells consumed, fire self extinguished

Oxygen Generator Over Pack Test Lithium Metal Cells

Oxygen Generator Over Pack Test Lithium Metal Cells

Oxygen Generator Over Pack Test Lithium Metal Cells

- **Results: Wire reinforced taping with 1” diameter pressure relief/ flame arrestor**
  - 7:36, first vent/thermal runaway, smoke from Pressure Relief Vent
  - 11:07 multiple vents, continuous smoke from PRV
  - 11:19 smoke / gas ignite at PRV
  - 11:51 box inflates, flame at PRV becomes torch
  - 12:03 multiple flame penetrations at box closures
  - 12:14 fiberboard ignited
  - 13:11 Flame at PRV diminishing, last cells reach thermal runaway
  - 19:36 over pack and cells consumed

Oxygen Generator Over Pack Test Lithium Metal Cells

Oxygen Generator Over Pack Test Lithium Metal Cells

Oxygen Generator Over Pack Test Lithium Metal Cells

Future Tests

- **Button cell flammability characterization**
- **Lithium-ion low state of charge flammability characterization**
- **Packaging study for small shipments**
- **Full scale tests**

Contact Information

- **Harry Webster**
- **609-485-4183**
- **Harry.Webster@faa.gov**
- **www.fire.tc.faa.gov**