Development of Battery Packs for Space Applications

NASA Aerospace Battery Workshop
November 27 – 29, 2007

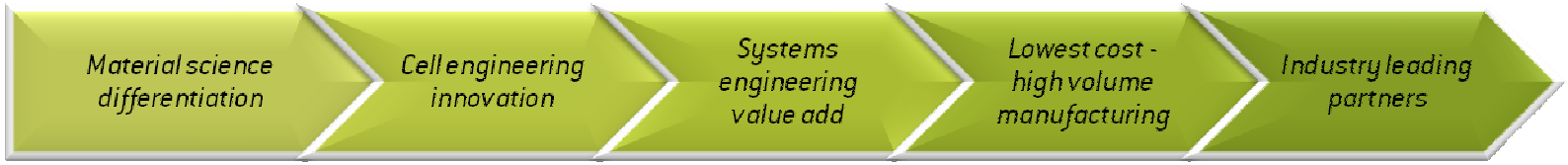
power. safety. life.™

About A123Systems

- A123Systems is an energy company founded at MIT in 2001.
  - Headquarters: Watertown, MA
  - Materials Research: Ann Arbor, MI
  - Pack and Systems: Hopkinton, MA
  - Hymotion: Toronto, Ontario

- We have developed a new generation of lithium ion batteries offering a quantum improvement in power, safety and life. This game changing technology is enabling a new age of cordless and transportation products.

- Core capabilities demonstrated:

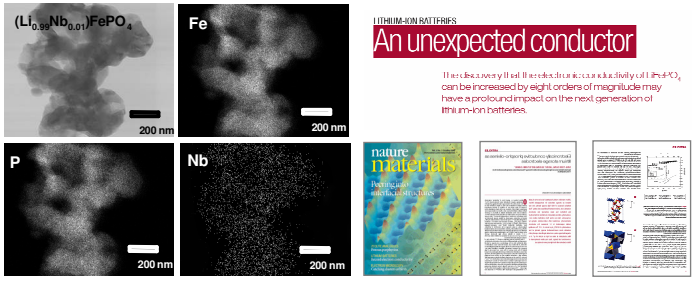


- The company has strong financial backing from investors. Since our inception, we have raised >$130M from companies like:

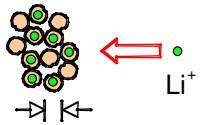
Core Technology Behind A123's High Power Chemistry

- A123 doped Nanophosphate™

Better battery enabled by new nano-materials (Nature Materials, 2002)

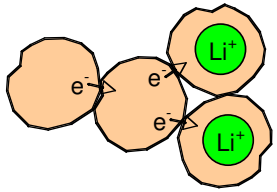


Nature Materials, 2002

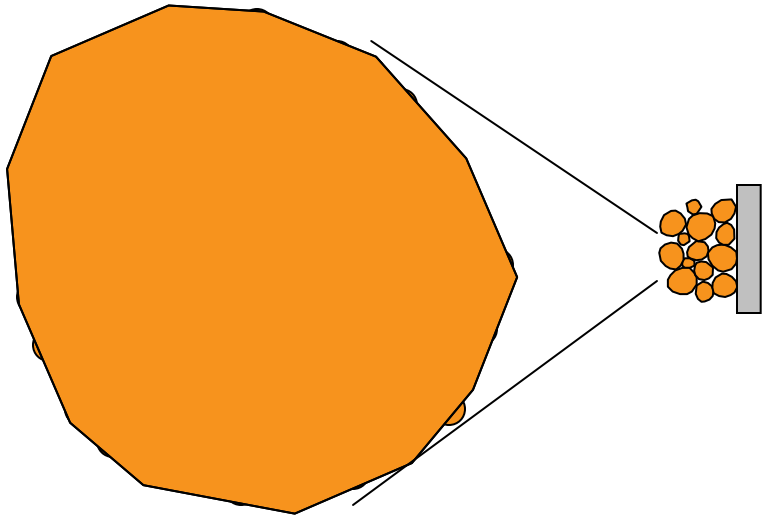


<0.1 micron

Nano particle size = extremely fast diffusion



Dopant significantly increases rate capability



~5 microns

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Cell Products

	APR18650	ANR26650	AHR32113	AHR32157
Cathode	Nanophosphate™			
Anode	Graphite			
Electrolyte	Carbonate-based, Li salt			
Capacity	1.1 Ah	2.3 Ah	3.6 Ah	8-10 Ah
Energy	3.6 Wh	7.6 Wh	12 Wh	25-32 Wh
Nominal Voltage	3.3 V			
Cell Dimensions	18 mm Φ x 65 mm high	26 mm Φ x 65 mm high	32 mm Φ x 113 mm high	32 mm Φ x 157 mm high

Safety

Conventional Lithium Ion

- Energetic thermal runaway above 150 °C
- Significant oxygen evolution
- Excess lithium can plate during overcharge
- Failure mode on overcharge:
  self-accelerating heat generation,
  potential explosion

A123Systems

- Significantly higher onset temperature and/or less heat evolution"
- Little or no oxygen evolution
- No excess lithium in cathode
  Overcharging will not plate Li
  (at proper current, temperature)
- Failure mode on overcharge:
  venting due to gas pressure

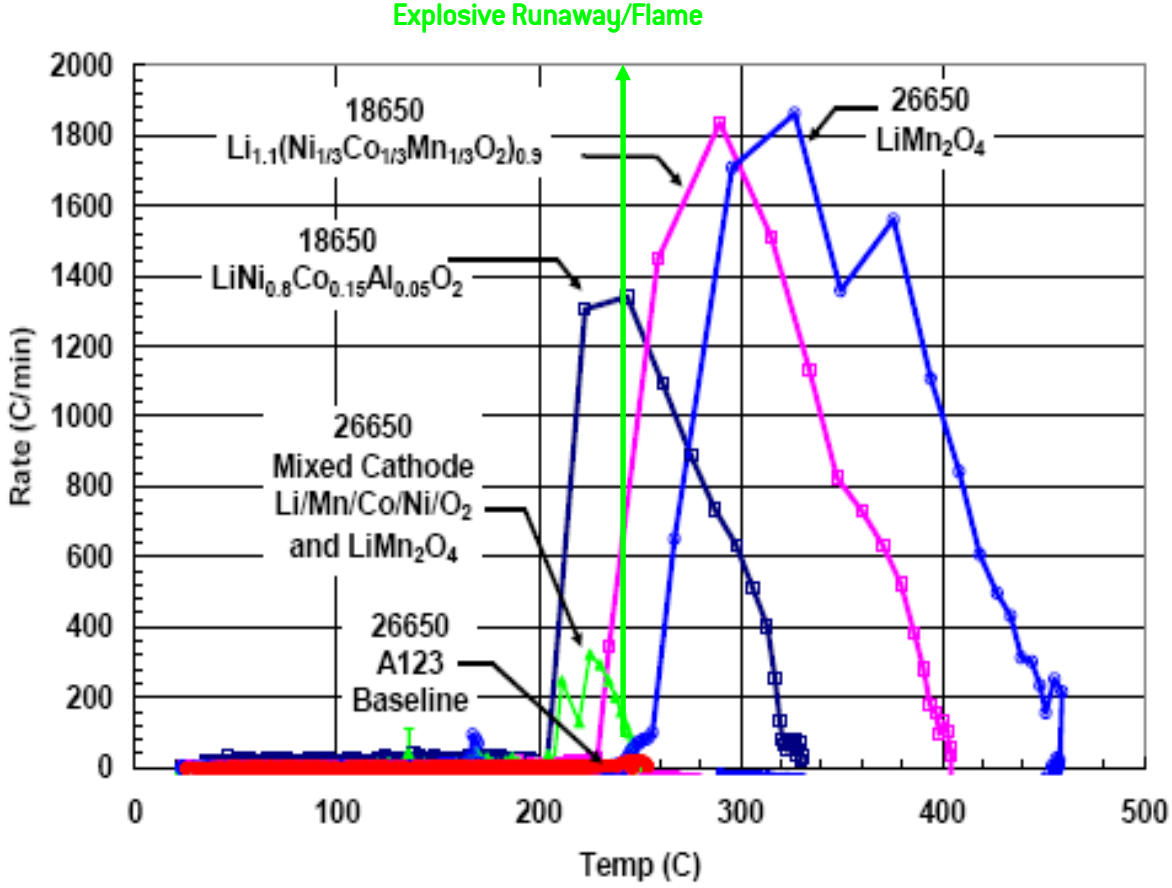
Cell and pack design can help delay onset of event, but do not change fundamental chemistry of system.

Abuse tolerance is particularly important for large packs because one cell failure can cause its neighbors to fail.

A123's doped Nanophosphate™ chemistry is more abuse tolerant.

Safety

Independent test results from Sandia



Data from Sandia Report:

"Thermal ramp Abuse Test Evaluation of Baseline A123 Cells"

E. Peter Roth, 9/07/07

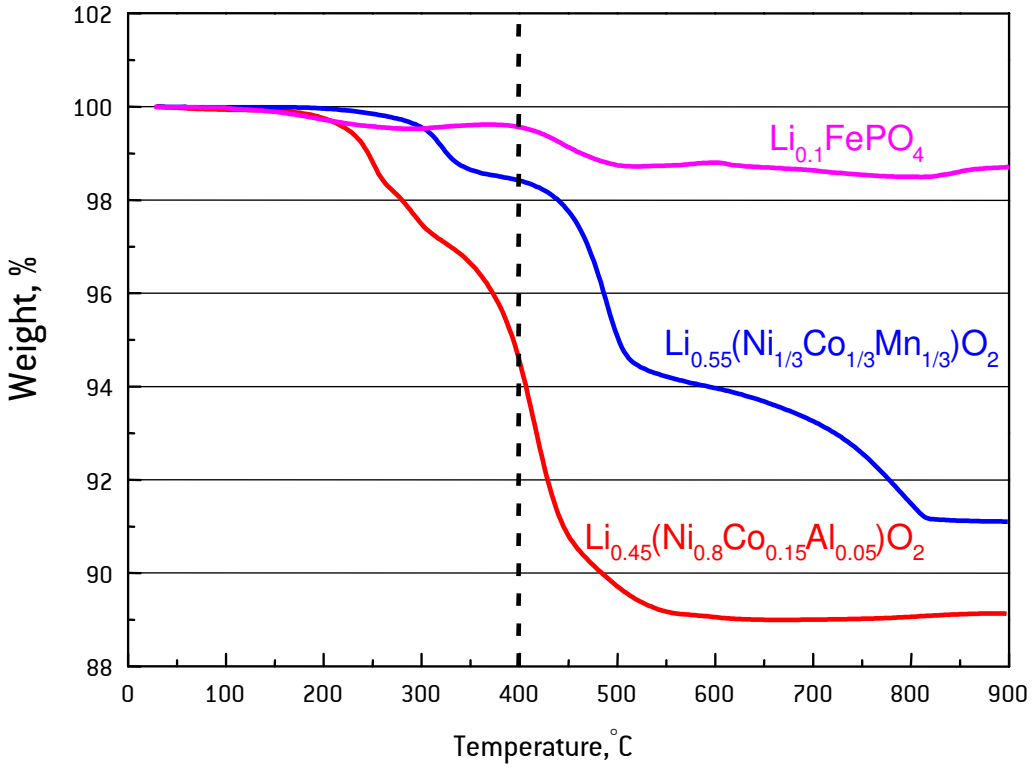
Figure 6: Heating rate profile comparison including additional common cathode compositions in 18650 cells.

Difference between technologies:

Chemical potential energy released through oxidation/combustion that creates energetic events.

$LiFePO_4$ Thermal Stability

- The TGA test of $LiFePO_4$ in contrast with NCA, or NMC, indicates the LFP less likely to release oxygen
  - Reduced potential for electrolyte oxidation during thermal abuse (Source: K. Amine, ANL, ATD Review April 2006)



Weight loss = oxygen evolution

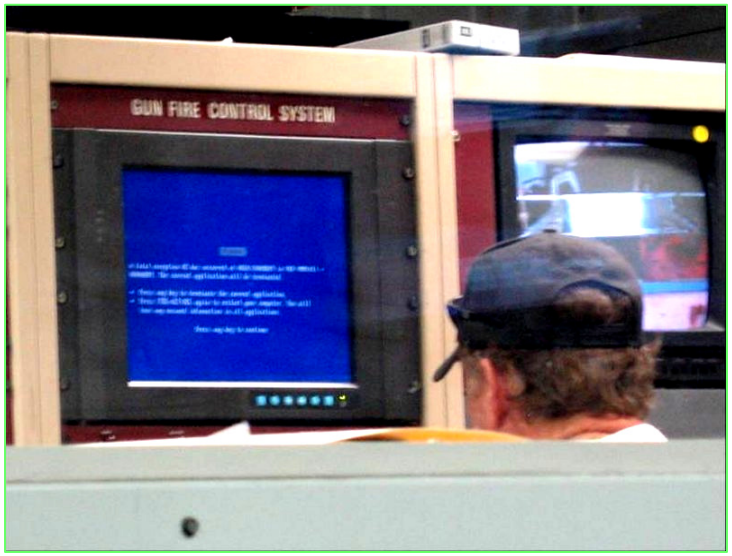
Phosphates in general have much better abuse tolerance than metal oxide cathodes.

A123's Nanophosphate is no exception.

Abuse Testing: U.S. Army, Ft. Eustis

Rifle Abuse Test (47 rounds) on Fully Charged A123 Pack; 26V

Before



After

No fire, no explosion

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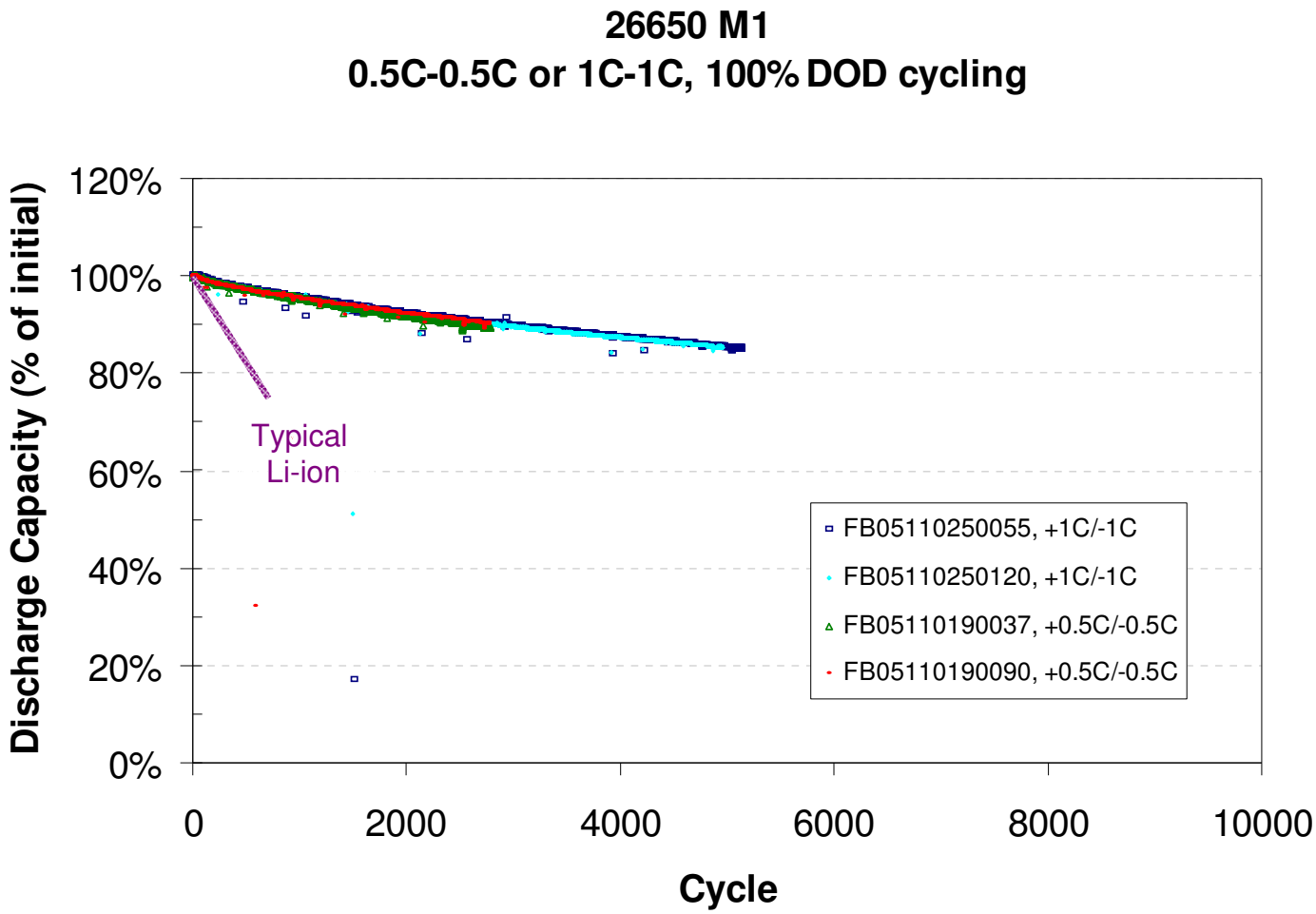
Low-rate 100% DOD Cycling of 26650*M1*



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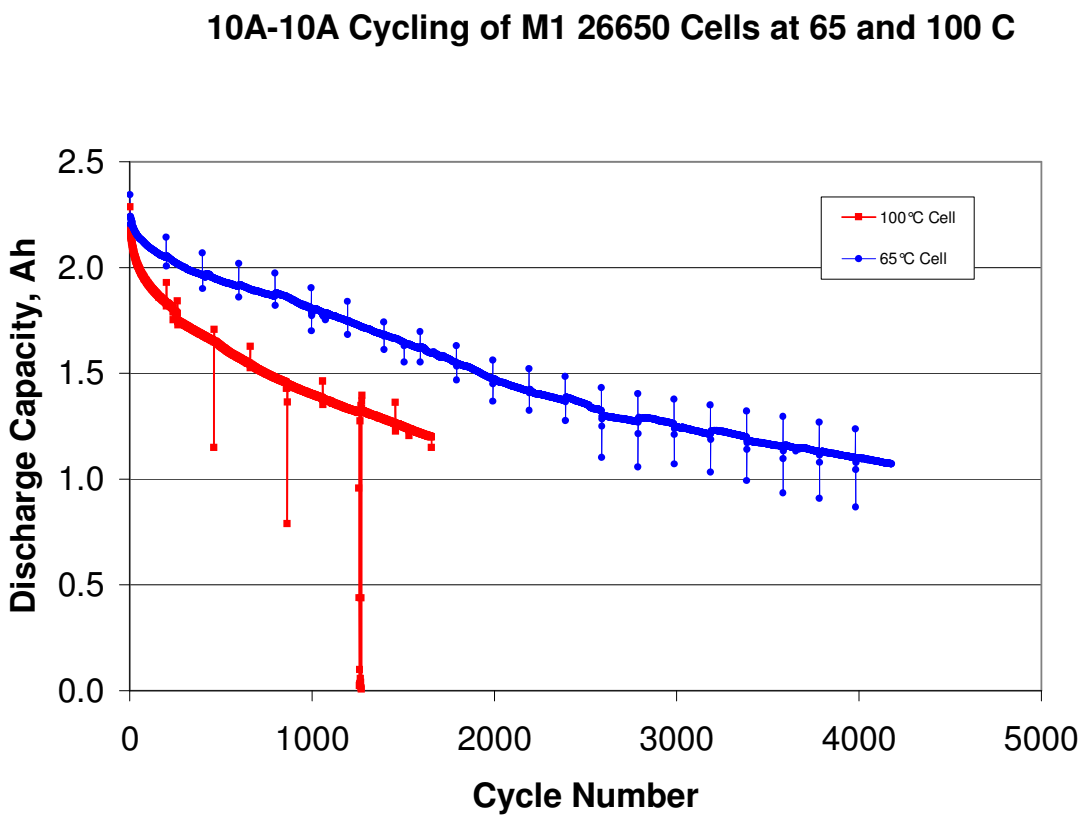
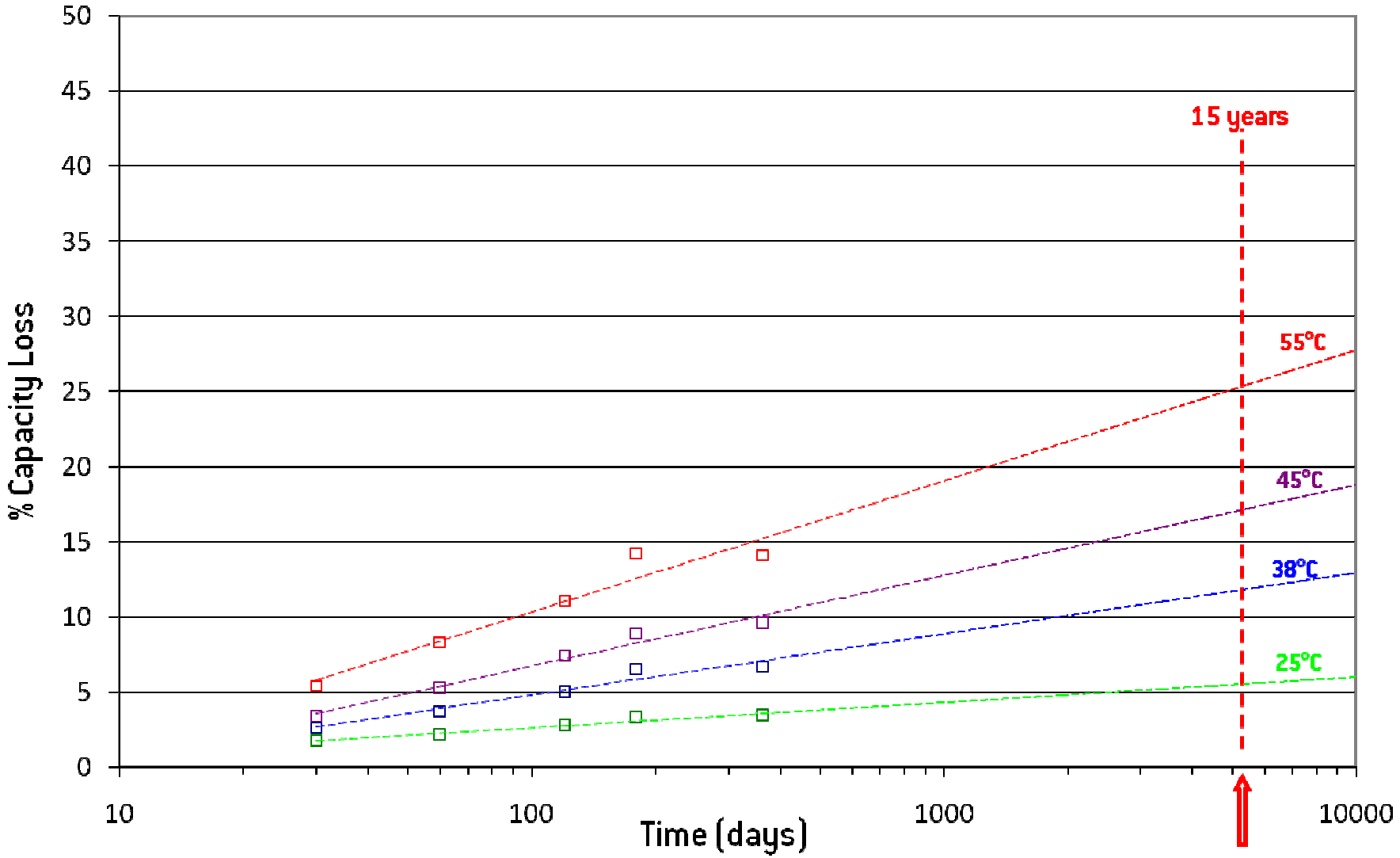
Excellent High-Temperature Cycling



Storage at 100% SOC



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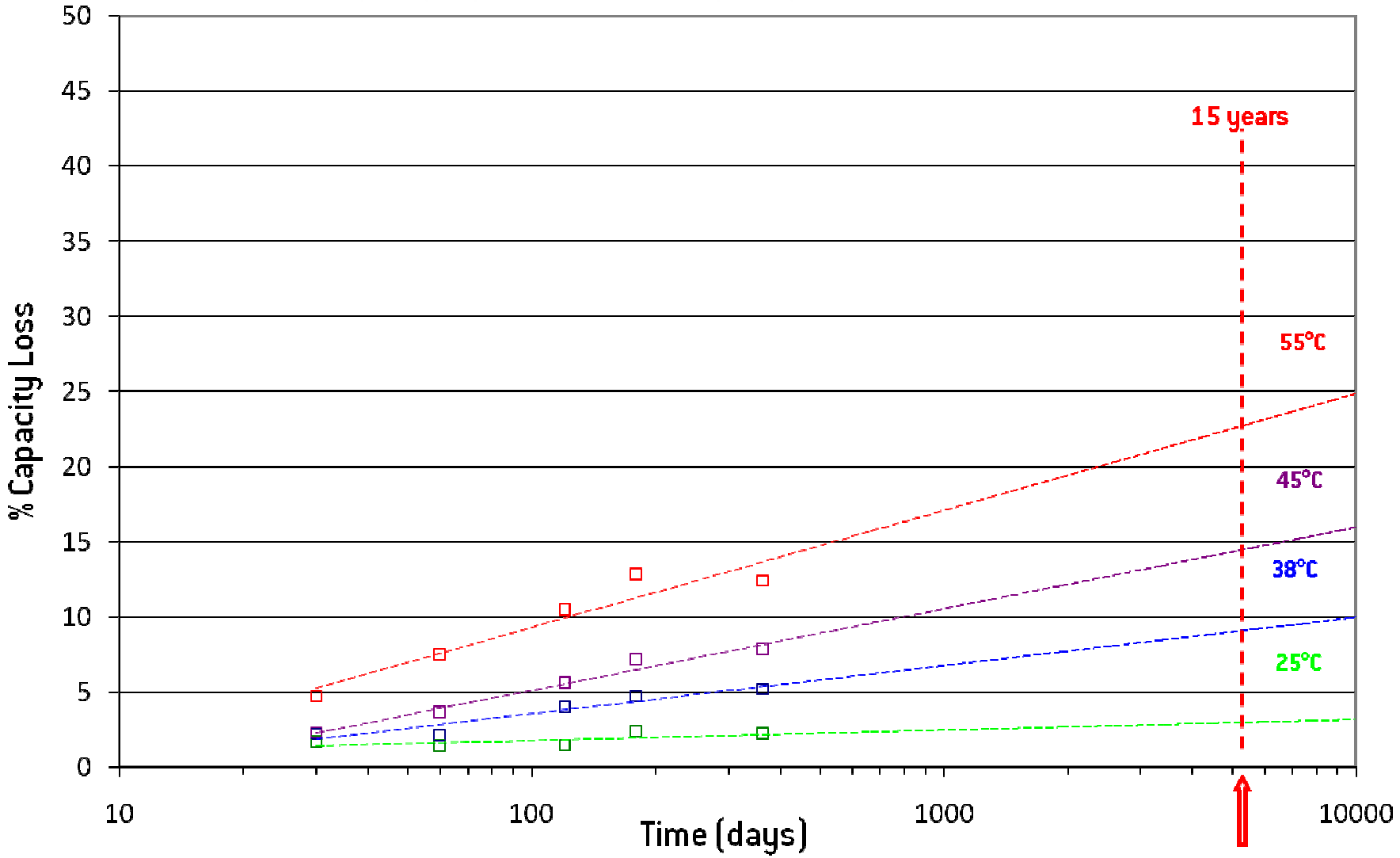
Storage at 50% SOC



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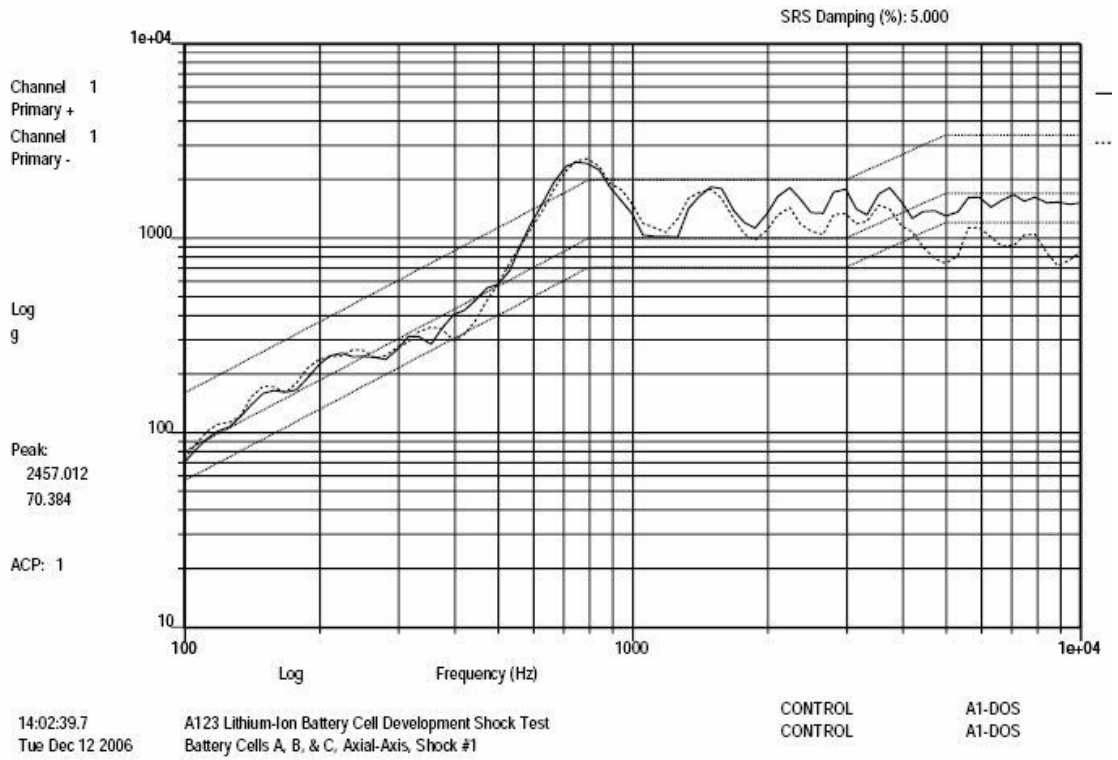
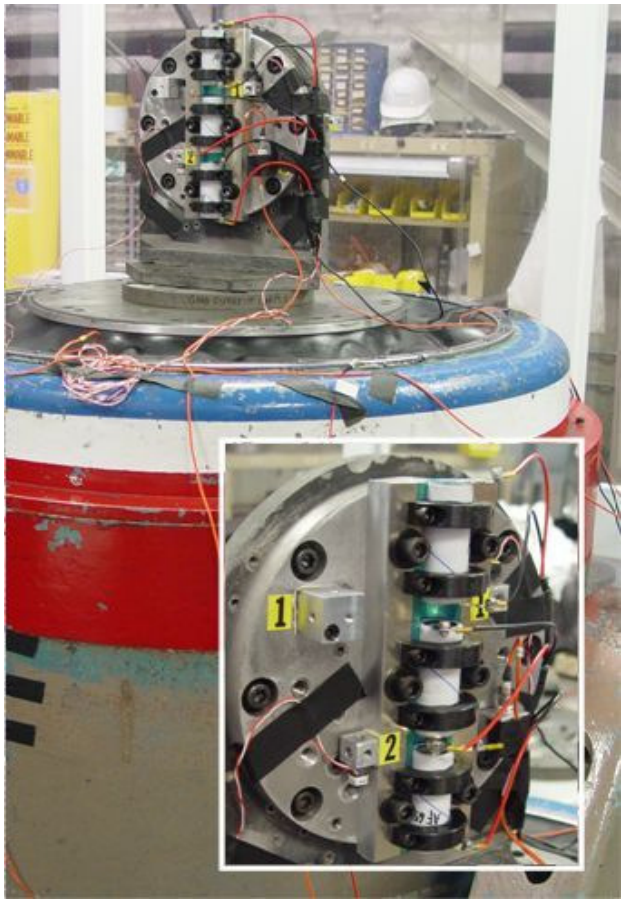
Cell Level Shock Testing Results

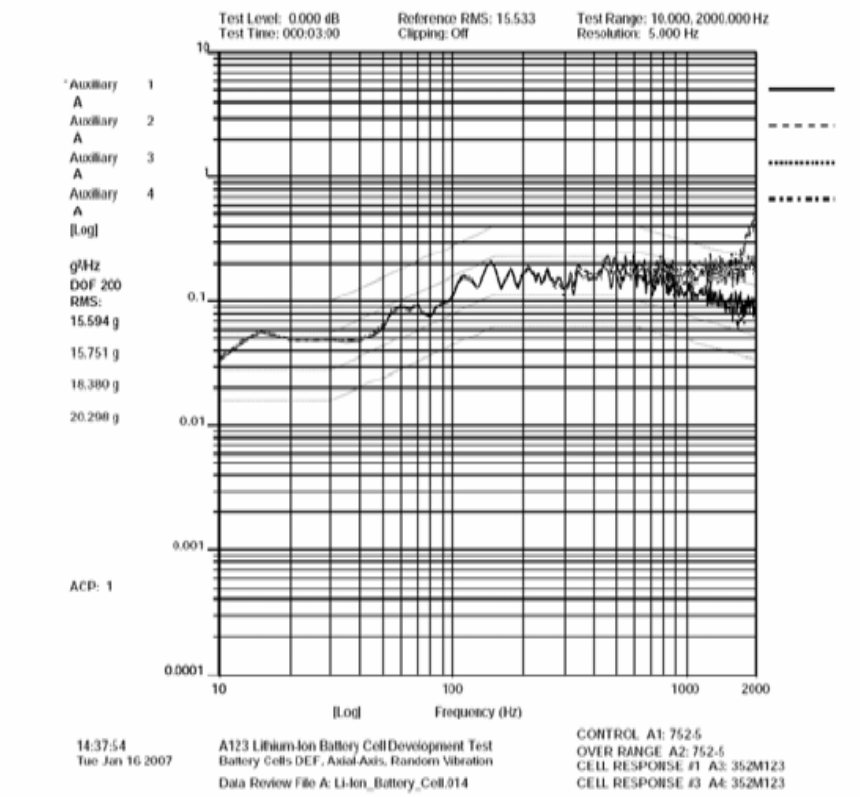
M1 cells have undergone Shock Testing:

- Each cell received 3 Launch Vehicle spectrum shocks on x, y, z axes.
- No voltage fluctuations or shorts recorded during tests.
- Minimal changes in capacity and impedance.

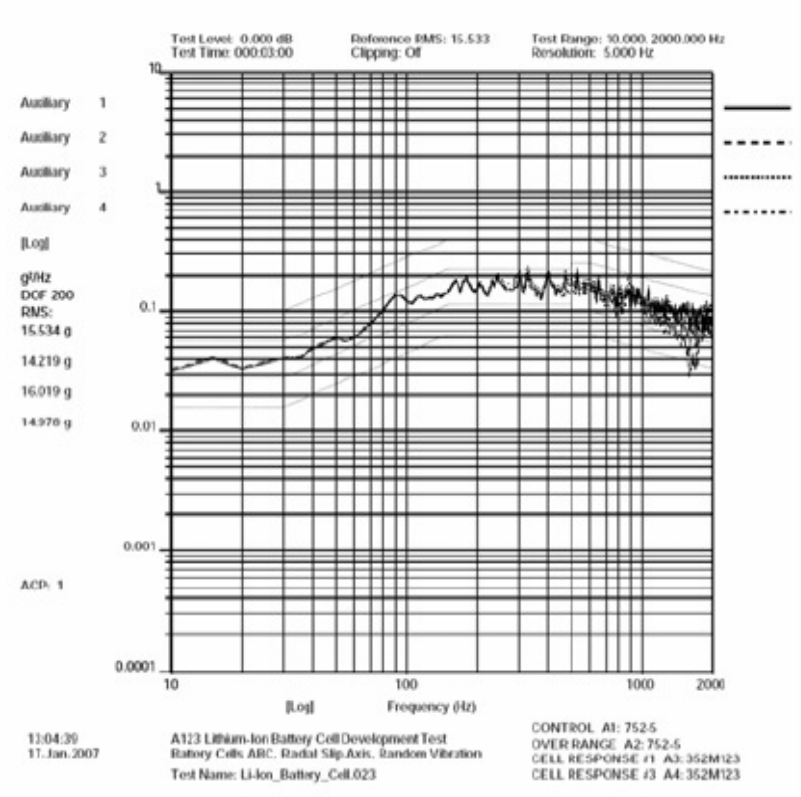




Random Vibration Test Results



Axial Response



Radial Response

11Ah 3.3V Nanophosphate™ Li-ion Prismatic Cells

- **Physical Overall Dimension:**

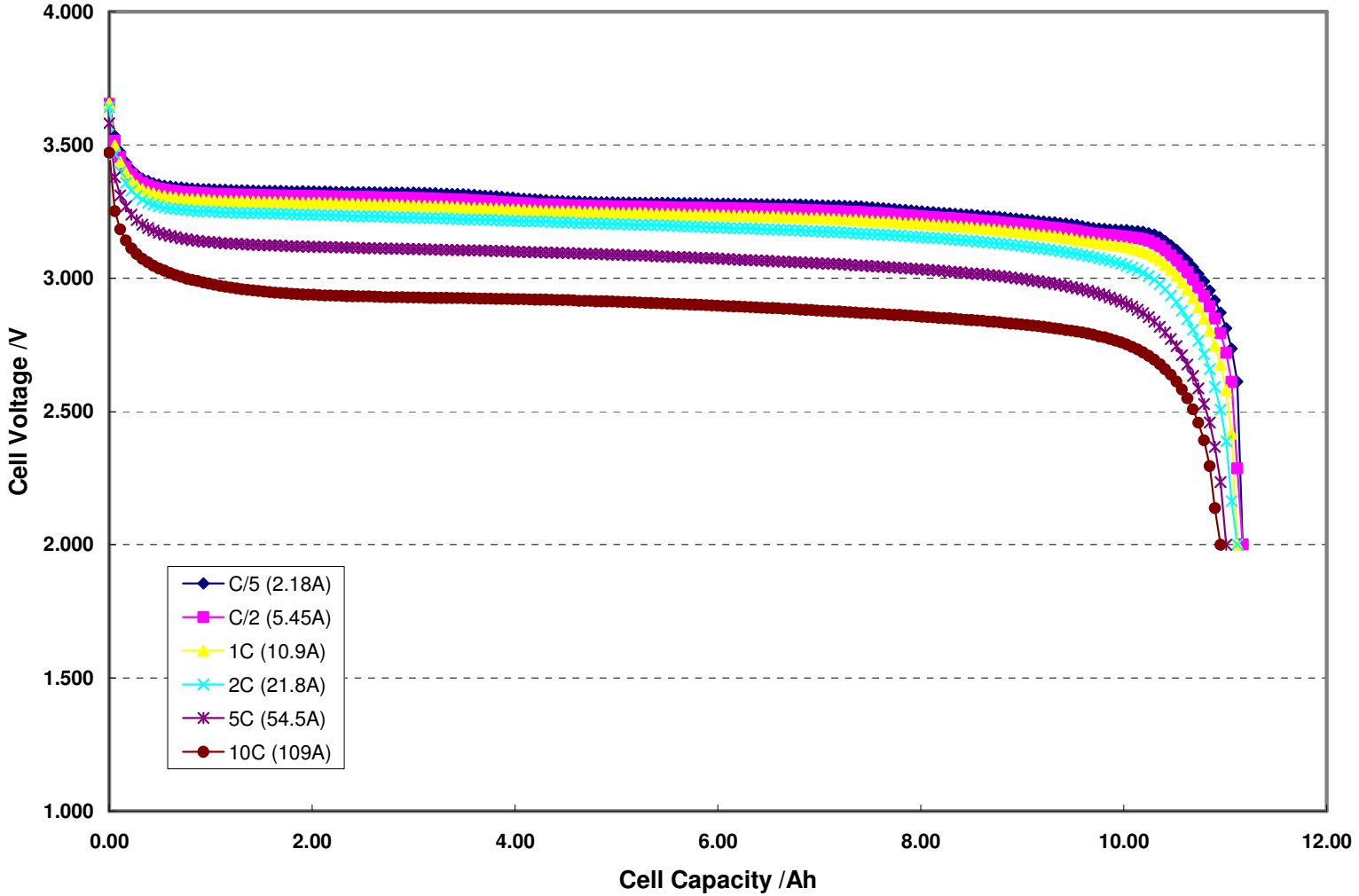
Length	10.2 cm
Wide	7.10 cm
Thickness	2.50 cm
Nominal weight	0.4 kg
Nominal volume	0.18 liter

- **Nominal Discharge Voltage at 0.2C:** 3.3V
- **Nominal Capacity at 0.2C:** 11Ah
- **Specific Energy:** 91 Wh/kg
- **Energy Density:** 202 Wh/L

Performance Comparison of 11Ah Prismatic vs. 2.3Ah M1 Cylindrical

- Discharge Rate Capability
- High Temperature Storage
- Cycling Stability at High Temperature
- Low Temperature Performance

Discharge Rate Capability of 11Ah Prismatic Cells



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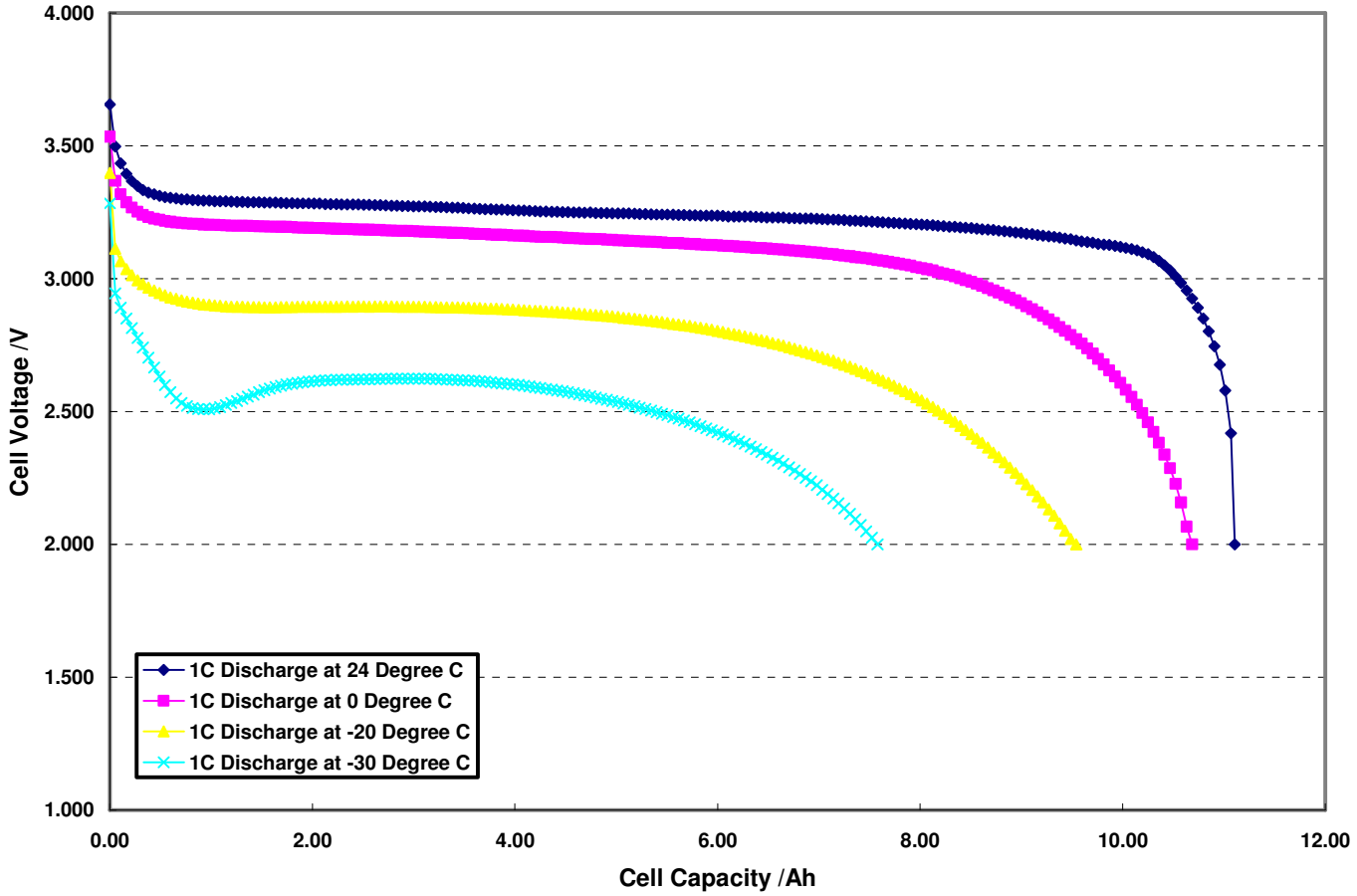
Comparison of Discharge Rate Capability
11Ah Prismatic vs. 2.3Ah Cylindrical

Cell ID#	0.2C Discharge Capacity /Ah	10C Discharge Capacity /Ah	Capacity Retention /10C Cap./0.2C Cap.
PR-11Ah-1634	10.91	10.75	0.985
PR-11Ah-1635	11.16	10.96	0.982
PR-11Ah-26650*	2.317	2.312	0.998

*: Average of fifteen 2.3Ah 26650 cylindrical cells.

Low Temperature Performance of 11Ah Prismatic with Standard Electrolyte



The cells were charged with CC (constant current) at C/5 to 3.8V and then CV (constant voltage) at 3.8V until the current decreased to C/20, and then discharged with CC at 1C. Both charge and discharge processes were performed at the same temperature.

Aerospace, Defense Applications

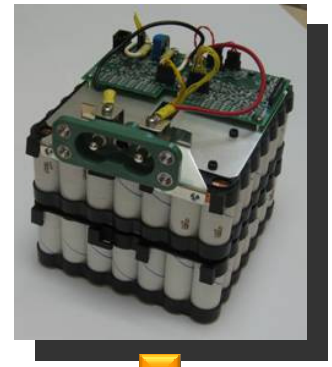
A123's technology enables applications requiring power, safety, and life.

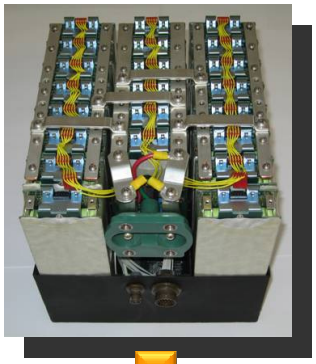
- **High power pulse capability**
  High gravimetric and volumetric power density enables pulse applications (e.g. communications and directed energy weapons).
- **Fast charge with high energy density**
  A123's technology can be charged to >90% SOC in less than five minutes, yet retains high specific energy and energy density.
- **Highly abuse tolerant technology minimizes chance of cascading failure**
  Well-suited to applications where individual cells might experience damage (e.g. combat).
- **High cycle life**
  A123's excellent calendar and cycle life may allow higher % DOD, thus increasing *useable* energy (e.g. satellites).
- **High efficiency and low thermal signature**
  High power = high efficiency. A123's technology minimizes losses from waste heat generation.
- **Low self-discharge, high reliability**
  A123's technology has low self-discharge, allowing the device to sit idle for several months, yet still function when needed (e.g. remote sensing).

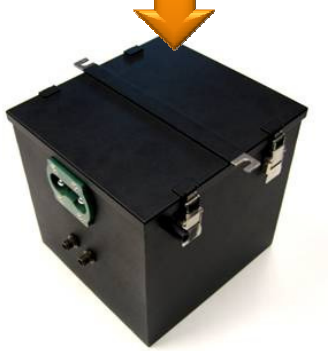
Pack & Systems Engineering

- Mechanical submodule and pack design
  - Mechanical Protection
  - Thermal Management
- Battery Management Systems
  - Hardware
  - Software
  - SOC/SOH/Communications
  - Safety/Operation
- Testing
  - Design Verification
  - Industry Standards
  - Customer Specifications

A123's Pack & Systems Group:
From 3V to 750V and 2Ah to 55Ah

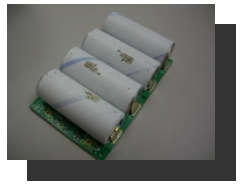






Aviation

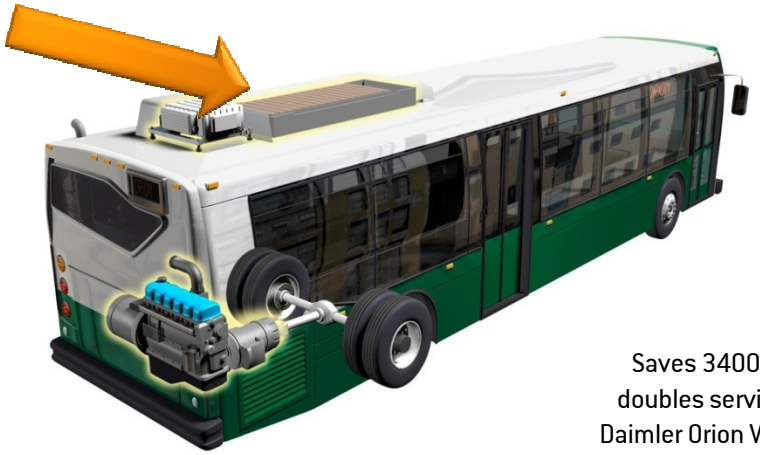
Small Trucks
(100kW HEV Pack)



High-power
Lead-acid
Replacements

BAE Systems

- BAE Systems will be offering A123Systems' lithium ion battery technology as part of its HybriDrive® propulsion system.
- The next-generation HybriDrive system featuring A123Systems batteries will be available for commercial buses beginning in 2008.
- BAE Systems' HybriDrive propulsion system is available on the Daimler Orion VII hybrid transit bus. The system is in use in three of the four largest hybrid bus fleets in the world today.



Saves 3400lbs and doubles service life of Daimler Orion VII HEV Bus

General Motors in PHEV and EREV

World's first commercial plug-in program by major OEM announced January 2007

Two battery development contracts awarded January 2007:
A123, Johnson Controls-Saft

Revolutionary series hybrid design concept announced January 2007

Two battery development contracts awarded June 2007:
A123, Compact Power-LG

GM now targeting abuse-tolerant, potentially low-cost lithium ion technologies

Conclusions

- power. safety. life.
- Core capabilities
  - Materials
  - Cell
  - Pack
- A123's technology *enables* new applications

Contact information

- Les Alexander

734-213-1637 x 10

lalexander@tjtechnologies.com

- Suresh Mani

734-213-1637 x 18

sureshmani@tjtechnologies.com

- David Carmen

734-213-1637 x 45

dcarmen@tjtechnologies.com

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