

Recent Advances with Lithium Carbon mono-fluoride Batteries for Portable Applications

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Topics

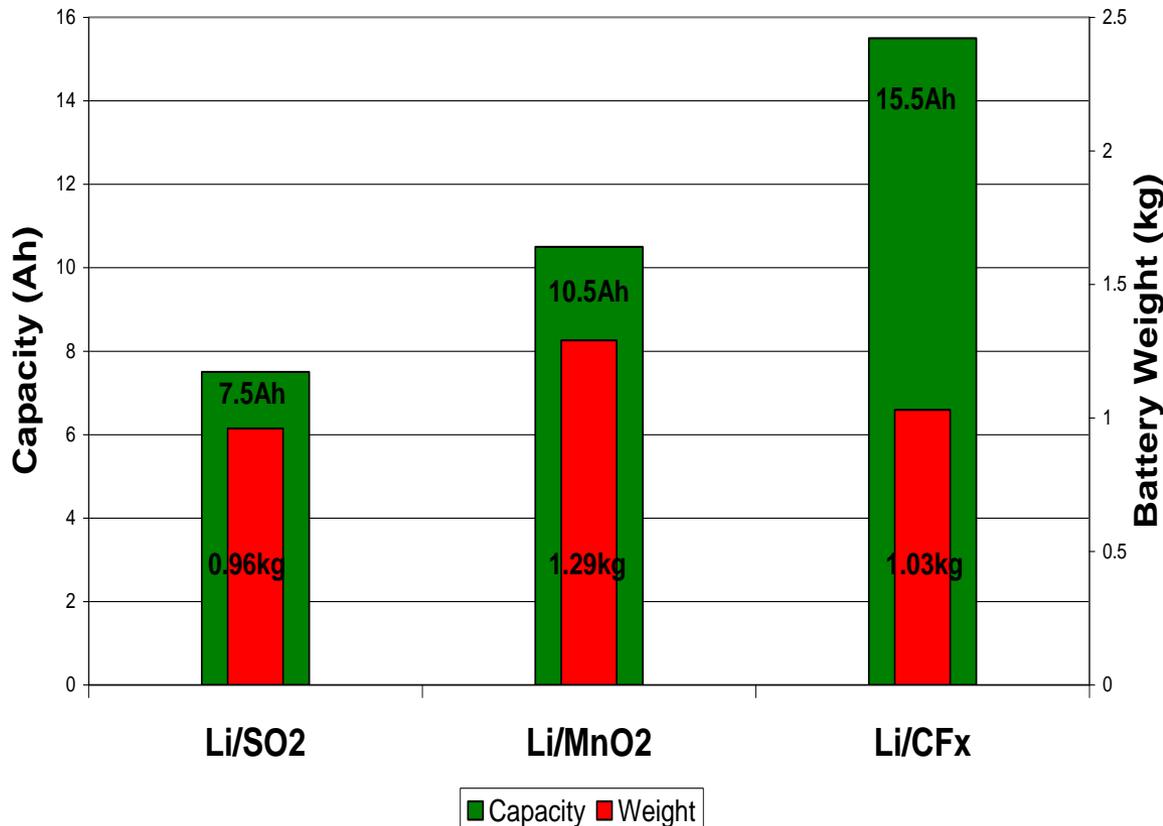
- **Introduction to Li/CFx**

- **“Half-Sized” BA-5590 Li/CFx Battery Development**
 - **Phase I – Steel Cell Development and Limited Battery Testing.**

 - **Phase II – Aluminium Cell Development and Additional Safety and Battery Testing.**

- **Conclusions**

- Initial target is a D cell with 2X Specific Energy compared to the current Li/SO₂ and Li/MnO₂ batteries at the required 2A continuous discharge rate.



Half BA5590
1/2 size / similar energy

- **Low temperature performance and heat management are recognized as the major challenges for this application.**
- **Significant improvements have been made in low temperature performance, but initial voltage delay still needs improvement for low temperature high rate applications.**
- **Heat management at the BA-5590 battery level is still a concern for high rate continuous operation.**
- **CFx material cost continues to be a concern for high volume applications.**

- **Aluminium hardware provides an increase of >100 Wh/kg in specific energy density.**
 - Reduction by 21% in weight.
- **Welded design with rivet seal provides a robust design for high temperature operation.**
- **Extensive performance, safety and transportation testing has been successfully completed with this design.**
- **All UN transportation tests - 28 days desert cycle.**



**D cell with Al Hardware
Length = 54.6 mm
OD = 33.1 mm**

Phase I – ½ Sized BA-5590 Li/CFx

- **Mild steel cell enclosure.**
- **Standard feed through and welding processes.**
- **Proof of Concept.**

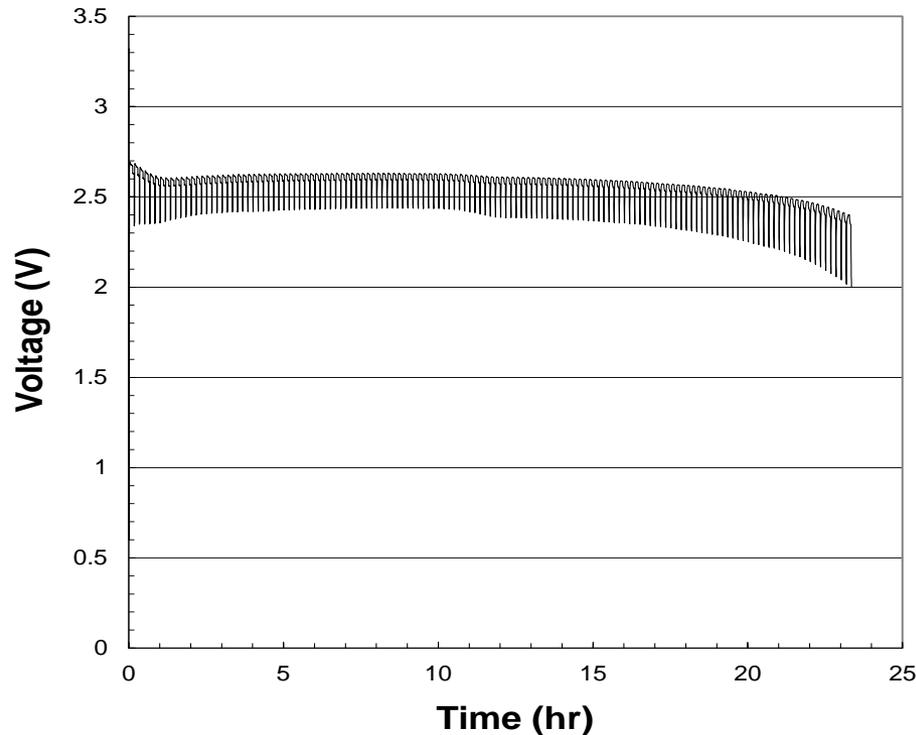
Attribute	US Army Performance Specification (Half-90)	EaglePicher Energy Products Half-90 Performance
Energy	200 Wh at SINCGARS (30.5 hours)	170 Wh at SINCGARS (26.2 hours) Ambient 184 Wh at 55°C
Weight	1.1 pounds (0.499 kg) (400 Wh/kg)	1.07 pounds (0.485 kg) (350 Wh/kg)
Dimensions	2.450" x 2.500" x 4.400"	2.435" x 2.490" x 4.390"
Voltage	16.8 V (10V cut-off)	16.5 V (10V cut-off)
Connector	BA-5590 Type	BA-5590 Type
Fuel Gauge	State of Charge Indicator	State of Charge Indicator
Operational Temperature	-20°C to 55°C	-20°C to 55°C (voltage delay noted at -20°C)
Storage Temperature	-40°C to 70°C	-40°C to 70°C
Transportation and SAR	Required before FY09 Soldier use	UN Transportation Tests compliant; SAR testing is required for Phase II

Phase II – 1/2 Sized BA-5590 with Li/CFx Cells.

- **Phase II was focused on additional testing of the battery to understand performance and safety.**
- **Outlined potential of Aluminium hardware as an option.**
- **Program refocused to Aluminium hardware development (LC-3155 Slim D).**
- **There were some design change issues which had to be addressed but the major issues were welding related.**
- **Phase II also carried out more testing according to that outlined in the First Article Tests and Safety Assessment Report, but not a full FAT/SAR.**

- **Aluminium hardware provides a weight advantage but due to material selection there are some other concerns:**
 - **Rivet seal replaces a more conventional Glass to Metal seal.**
 - **Cell is 23% lighter when compared to the Phase I design.**
 - **Slim D cell has passed the UN Transportation requirements.**
 - **Slim D cell was tested for some FAT and SAR requirements.**

- Cells tested under the SINCARS Protocol after 28 Day Desert Cycle lost 2.1%Wh and 1.2% Ah.
- SINCARS discharge protocol at 21°C provided.

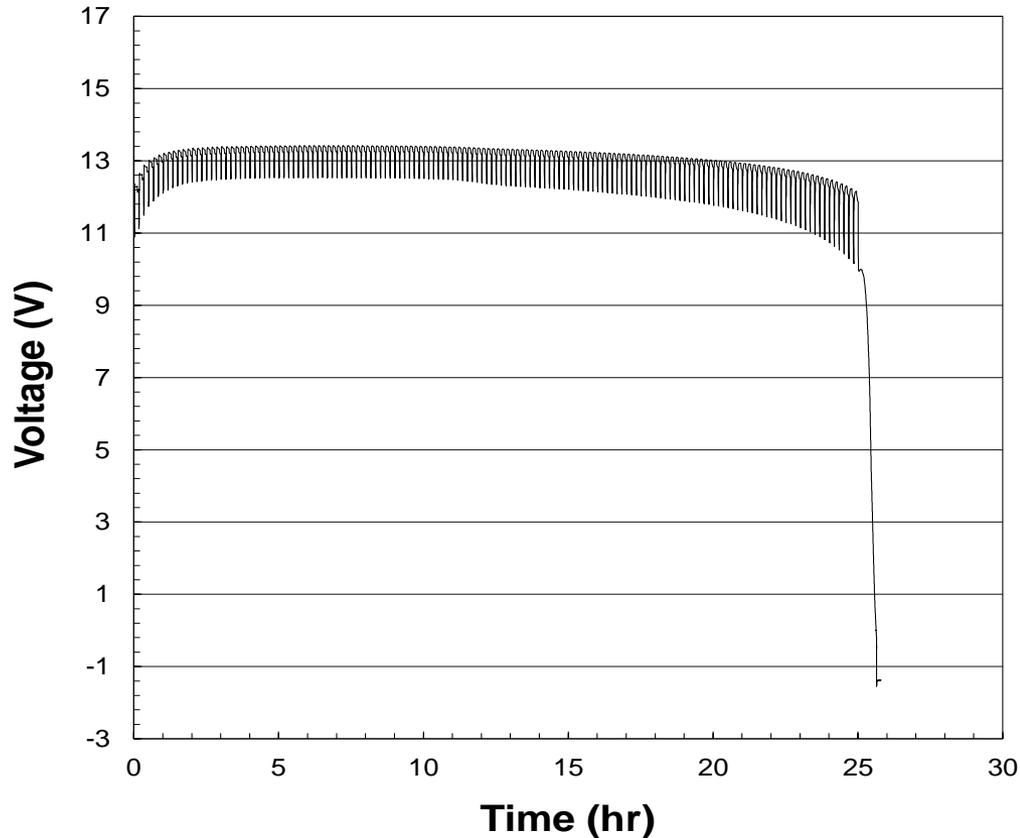


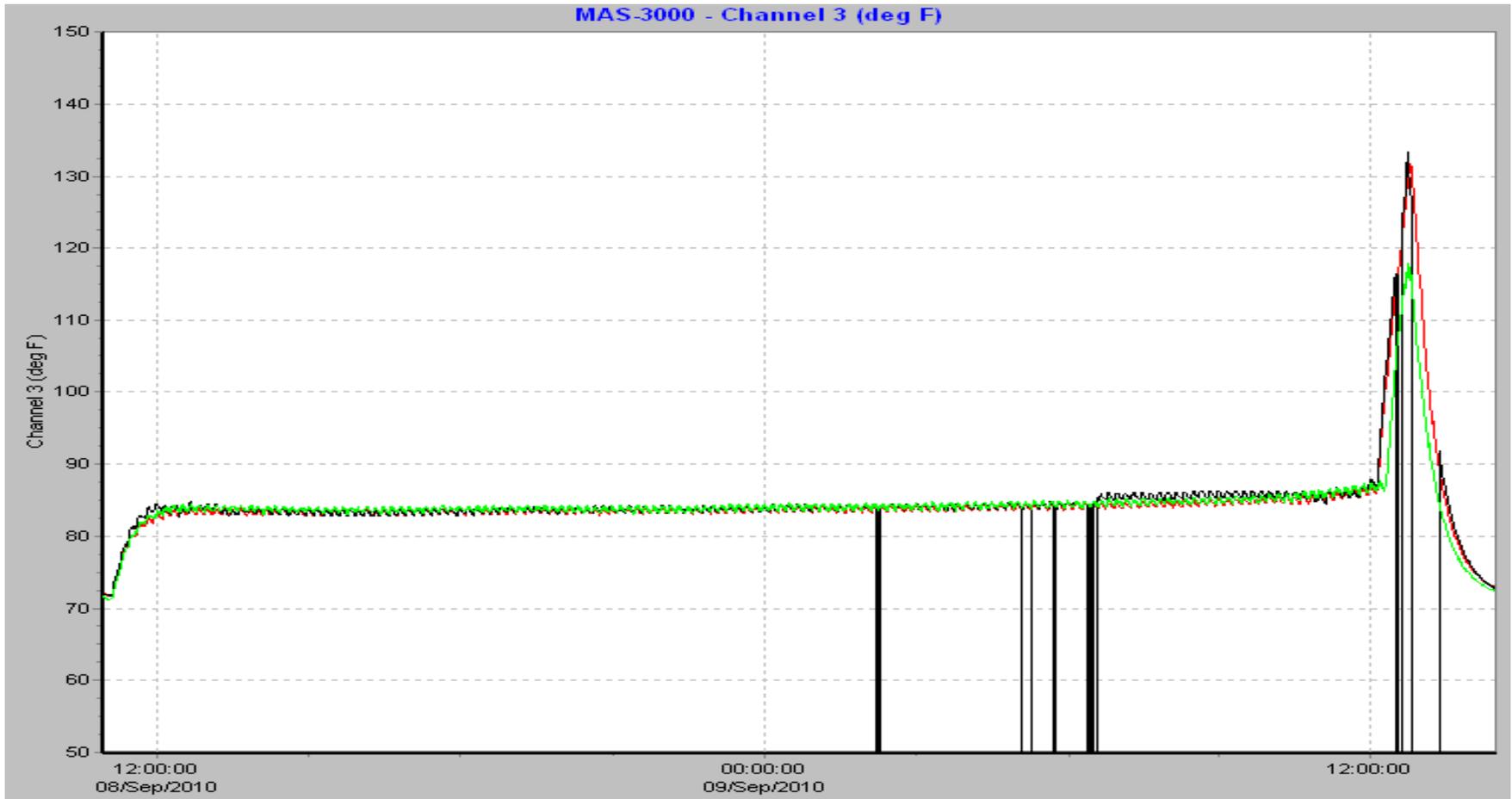
- **Aluminium Cells passed the following abuse tests:**
 - **UN Transportation Requirements:**
 - **T1 – T5 (Altitude, Thermal, Vibration, Shock, Short-Circuit).**
 - **T6 – Impact.**
 - **T8 – Forced Discharge.**
 - **Desert Cycle – Cell leakage.**
 - **Cell Charging - 20 mA for 96 hours.**
 - **Nail Penetration – 5 full penetration and 5 2/3 penetration**
 - **Full maximum of 107°C.**
 - **2/3 maximum of 137°C.**
 - **No fire or disassembly.**

- **Battery assembly was developed to deal with aluminium hardware.**
- **Battery weight was reduced by approximately 19%.**
- **Volume is 50% of the BA-5590.**
- **Finished battery now weighs < 400g.**
- **Weight is 41.1% of a BA-5590B/U**

- Under the I Test condition the battery delivered 164.6 Wh, 12.90-Ah and ran for 25.08 hours.

SINCGARS I Test



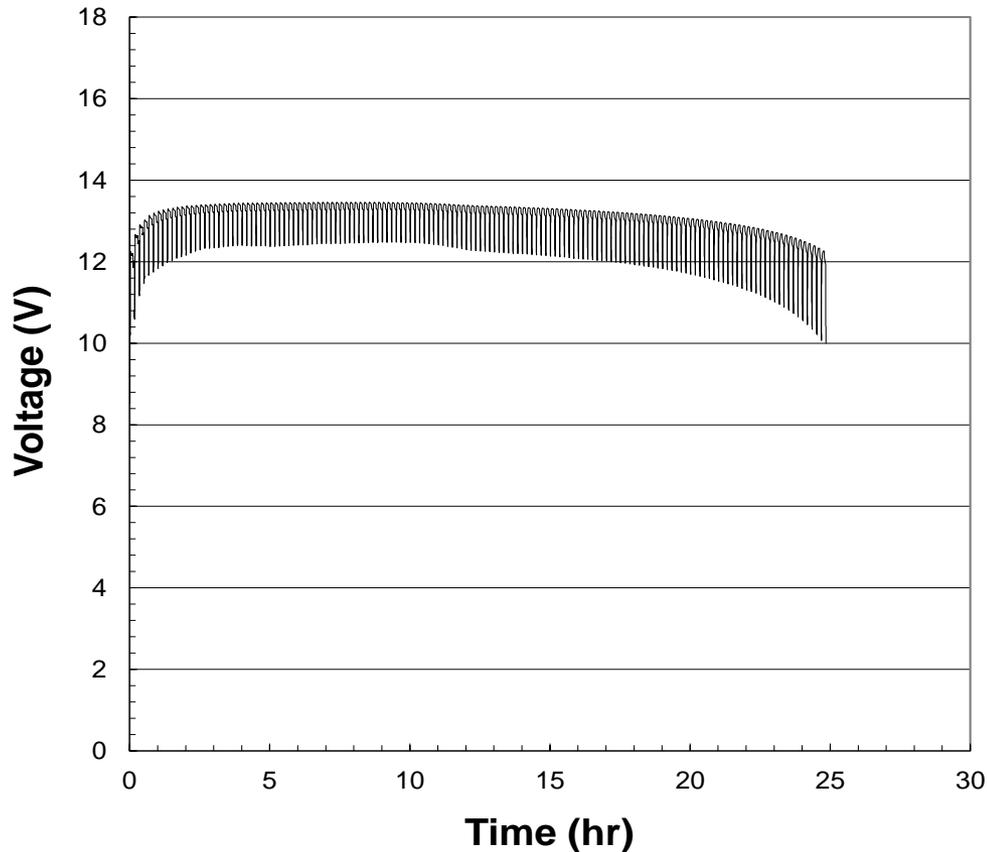


Company	Plot	Folder	Recording	Chan	Ch. Label	Type	Recording start	Recording size	Remark	Operator
EaglePicher		B590.AL CAPACITY	I	1	Channel 1	deg F	8 Sep 2010 (10:56:01 am)	9912 samples at 10 Secs		Robert Plucinski
EaglePicher		B590.AL CAPACITY	I	2	Channel 2	deg F	8 Sep 2010 (10:56:01 am)	9912 samples at 10 Secs		Robert Plucinski
EaglePicher		B590.AL CAPACITY	I	3	Channel 3	deg F	8 Sep 2010 (10:56:01 am)	9912 samples at 10 Secs		Robert Plucinski

- For the I Test 10 minutes FOD after 0V is required.
- Two of the batteries met this condition one did not.
- External Temperature reached a maximum of 134°F (56°C).

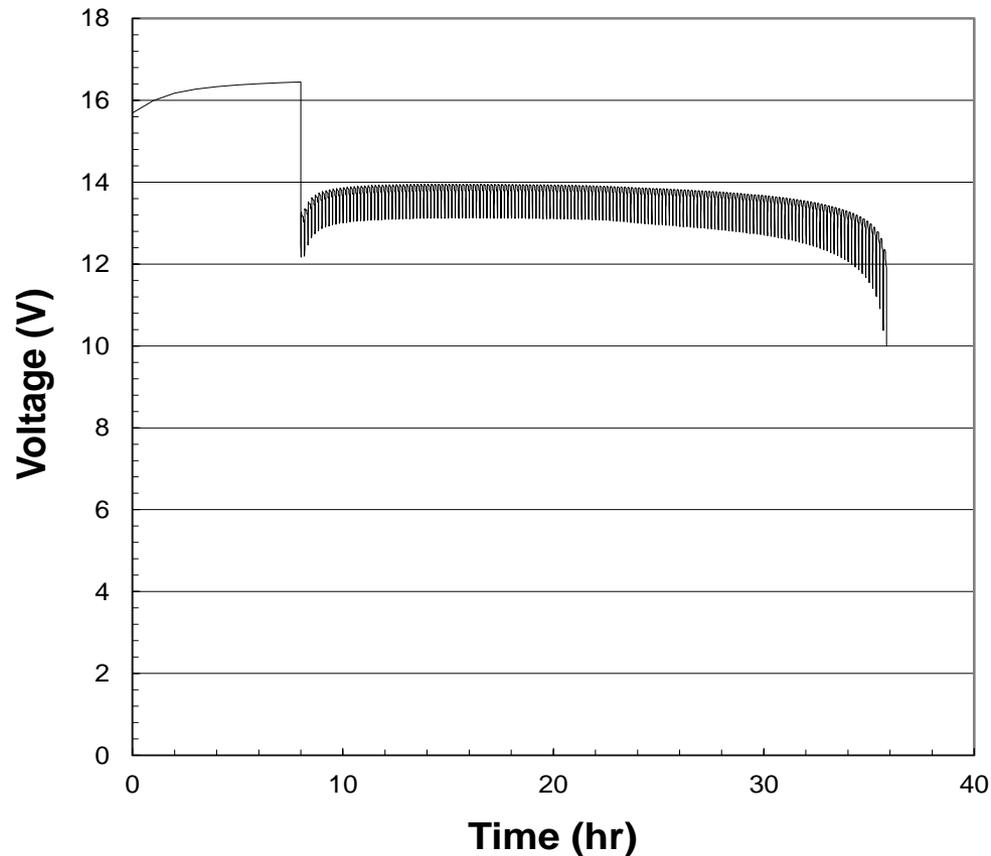
- Under the IT Test condition the battery delivered 164.9 Wh, 12.88-Ah and ran for 25.12 hours.

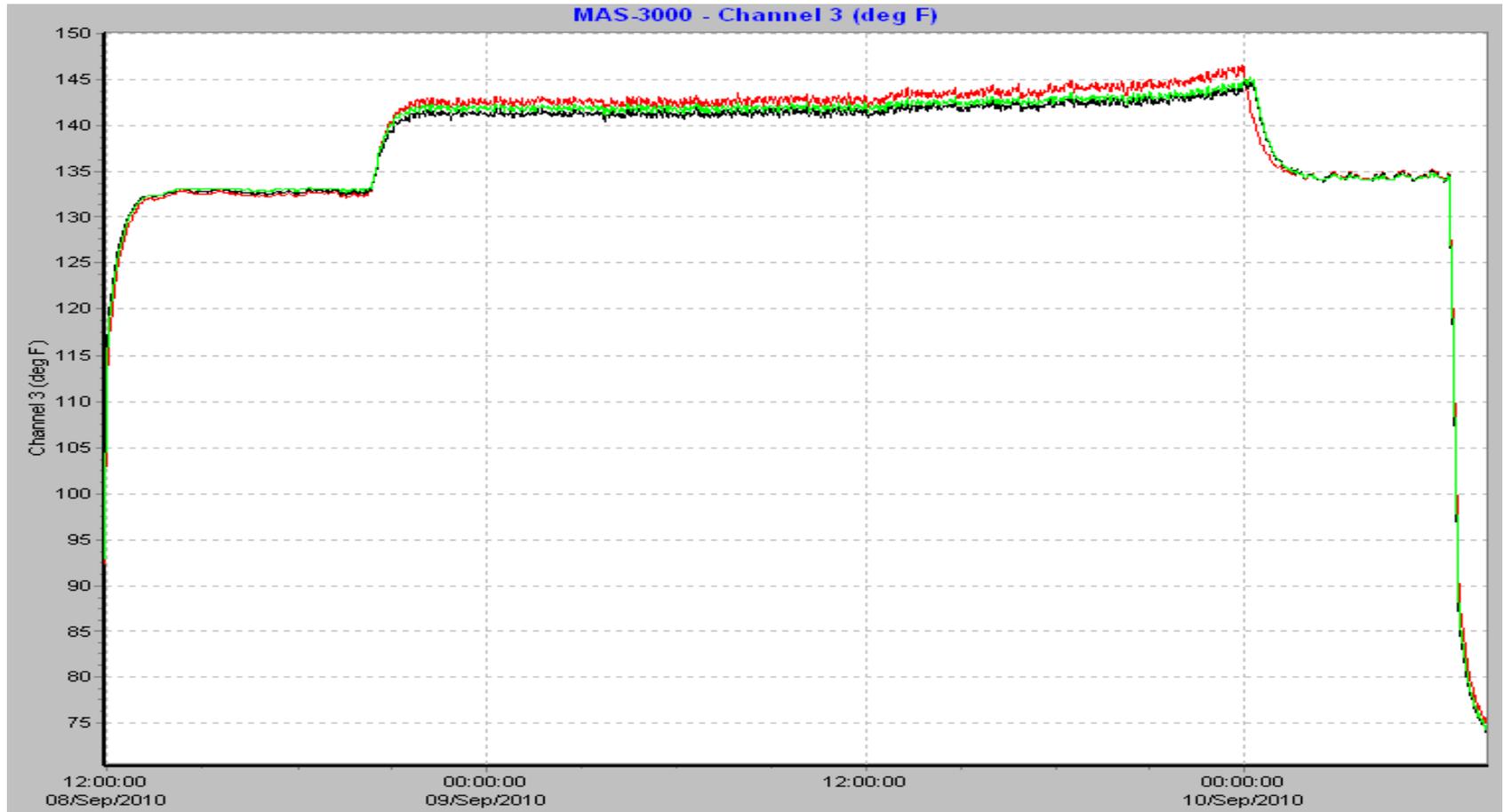
SINGGARS IT Test



- Under the H Test condition the battery delivered 181.9 Wh, 13.58-Ah and ran for 27.73 hours.

SINCGARS H Test



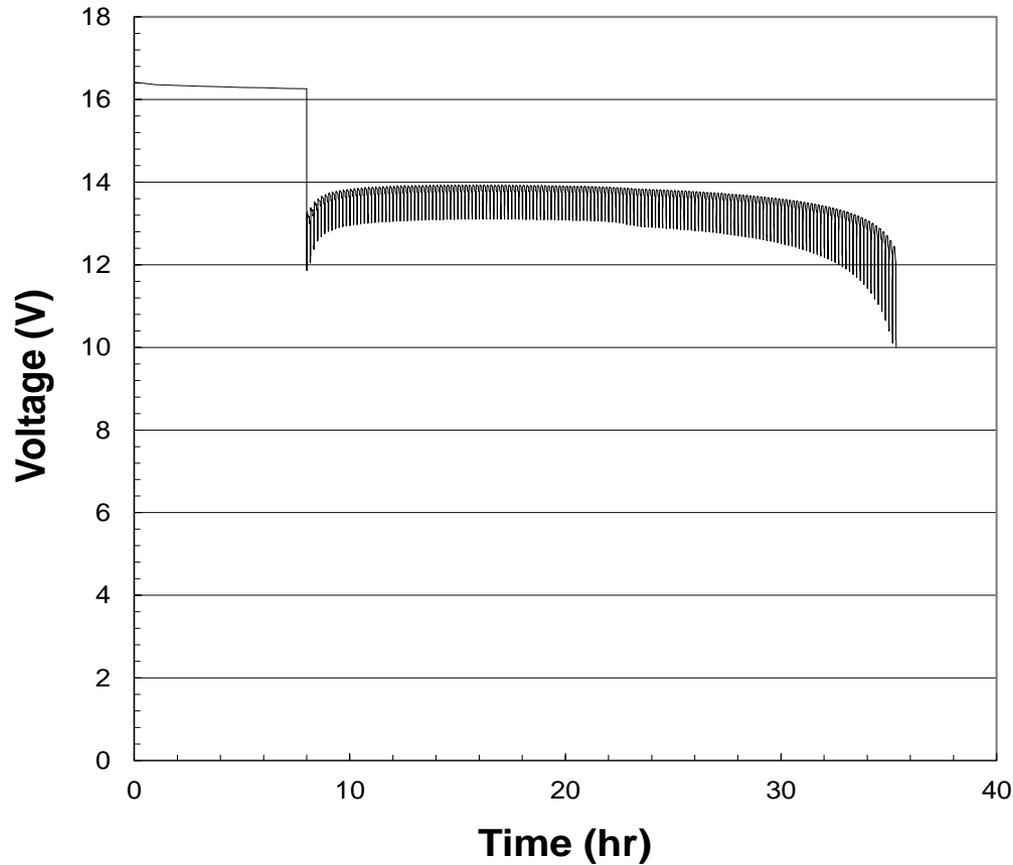


Company	Plot	Folder	Recording	Chan	Ch. Label	Type	Recording start	Recording size	Remark	Operator
EaglePicher		B590AL CAPACITY	H	1	Channel 1	deg F	8 Sep 2010 (11:55:52 am)	15738 samples at 10 Secs		Robert Plucinski
EaglePicher		B590AL CAPACITY	H	2	Channel 2	deg F	8 Sep 2010 (11:55:52 am)	15738 samples at 10 Secs		Robert Plucinski
EaglePicher		B590AL CAPACITY	H	3	Channel 3	deg F	8 Sep 2010 (11:55:52 am)	15738 samples at 10 Secs		Robert Plucinski

- No FOD Requirement.
- Maximum temperature reached was 146°F.

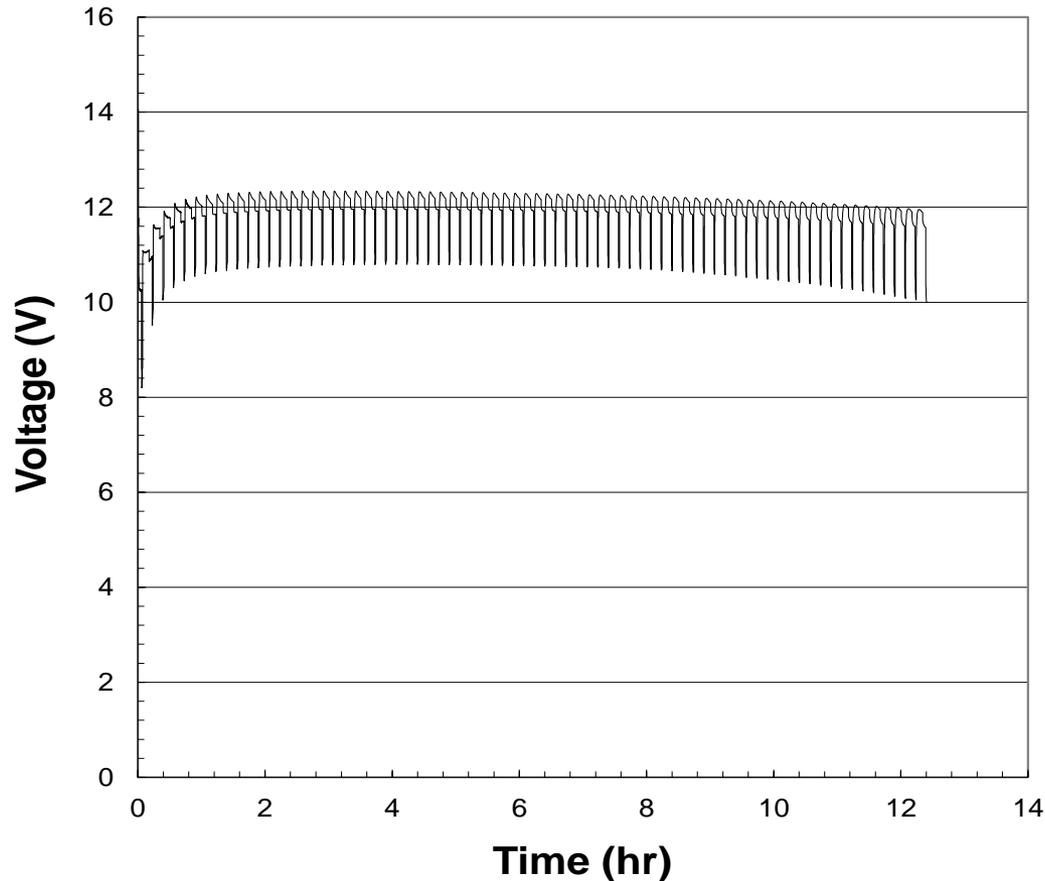
- Under the HT Test condition the battery delivered 179.8 Wh, 13.46-Ah and ran for 27.40 hours.

SINGGARS HT Test



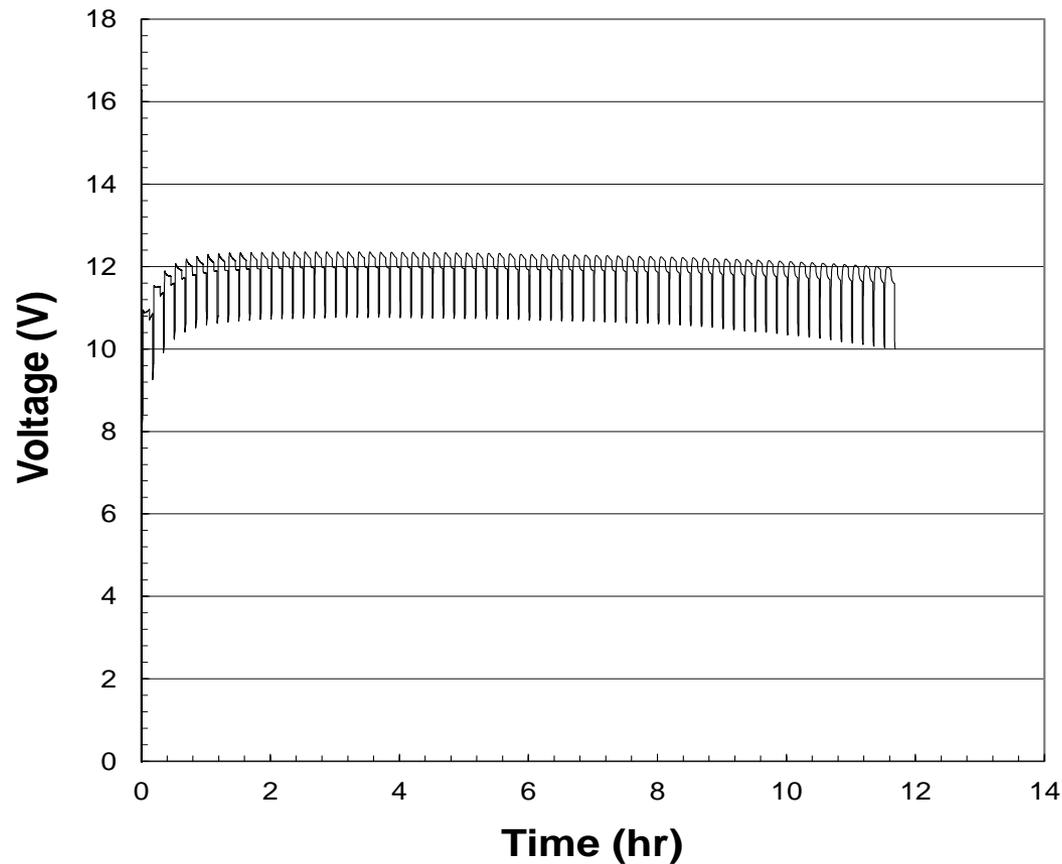
- Under the L Test condition the battery delivered 81.43 Wh, 7.07-Ah, 12.39 hours and 20 minute Voltage Delay.

SINGGARS L Test



- Under the LT Test condition the battery delivered 76.74 Wh, 6.65-Ah, 11.68 hours and 20 minute Voltage Delay.

SINGGARS LT Test



SINGARS Performance – ½ Sized BA-5590 No Storage (I, L and H)

Temp (°C)	Delay (min)	Min volt drop	Capacity (Ah)	Energy (watt-hrs)	Specific Energy (Wh/kg)	Energy Density (Wh/L)	Discharge time (hr)
-20	20	6.24	7.07	81.43	205.63	184.40	12.39
21	0.0	10.86	12.90	164.60	415.66	372.74	25.08
55	0.0	12.13	13.58	181.91	459.37	411.93	27.73

SINGARS Performance – 1/2 Sized BA-5590 After 7 Days Desert Cycle Storage (LT, IT and HT)

Temp (°C)	Delay (min)	Min volt drop	Capacity (Ah)	Energy (watt-hrs)	Specific Energy (Wh/kg)	Energy Density (Wh/L)	Discharge time (hr)
-20	20	0.00	6.65 (94.1%)	76.74 (94.2%)	193.54	173.78	11.68
21	0.0	8.88	12.88 (99.8%)	164.92 (100%)	415.42	373.46	25.12
55	0.0	11.94	13.46 (99.1%)	179.80 (99.85)	452.91	407.16	27.40

Phase II Performance versus Goals

Attribute	US Army Performance Specification (Half-90)	EaglePicher Energy Products Half-90 Performance
Energy	200 Wh at SINCGARS (30.5 hours)	165 Wh at SINCGARS (25.08 hours 21°C) 182 Wh at SINCGARS (27.73 hours 55°C)
Weight	1.1 pounds (0.499 kg) (400 Wh/kg)	0.87 pounds (0.395 kg) (415 Wh/kg)
Dimensions	2.450" x 2.500" x 4.400"	2.450" x 2.500" x 4.400"
Voltage	16.8 V (10V cut-off)	16.75 V (10V cut-off)
Connector	BA-5590 Type	BA-5590 Type
Fuel Gauge	State of Charge Indicator	State of Charge Indicator
Operational Temperature	-20°C to 55°C	-20°C to 55°C (voltage delay noted at -20°C)
Storage Temperature	-40°C to 70°C	-40°C to 70°C
Transportation and SAR	Required before FY09 Soldier use	UN Transportation Tests compliant; SAR testing is required for Phase II

- **High Energy D Size CFx cell has been developed with the energy and rate capability for the BA-5590 battery application**
 - 2X energy advantage over Li/SO₂ and Li/MnO₂.
 - Significant improvements in low temperature operation.
 - Aluminium hardware provides additional gain in specific energy.
- **Hybrid chemistry being developed by EPT Joplin offers the opportunity to expand technology to other applications**
 - Lower total battery material cost.
 - Improves voltage delay and heat management for portable power.