



Lithium Ion Battery Design and Safety

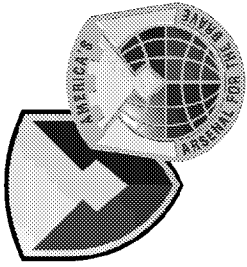
The NASA Aerospace Battery Workshop, Marshall Space Flight Center,
and the NASA Aerospace Flight Battery Systems Program
at Huntsville AL.

George Au and Laura Locke

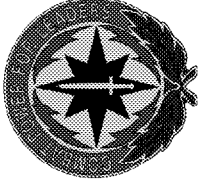
Presented by George Au
US Army CECOM RDEC
AMSEL-RD-C2-AP-BA
Fort Monmouth, NJ 07703
732-427-4886

George.Au@mail1.monmouth.army.mil
14-16 Nov. 2000

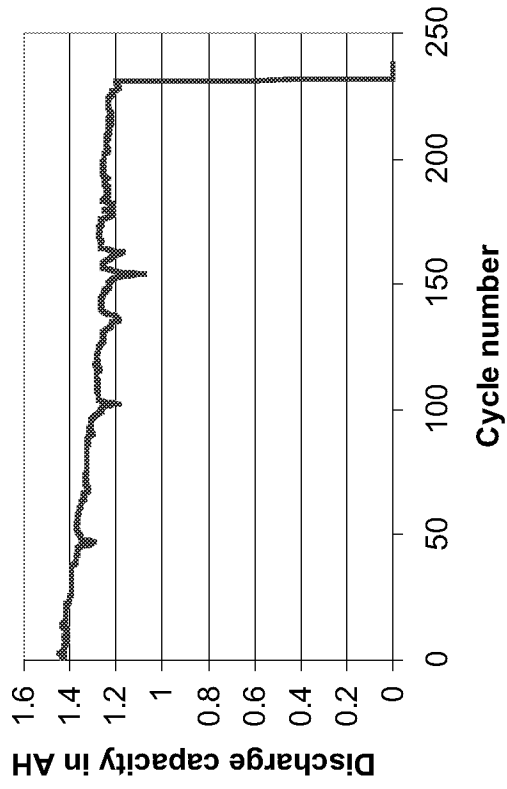
CECOM Bottom Line: THE SOLDIER



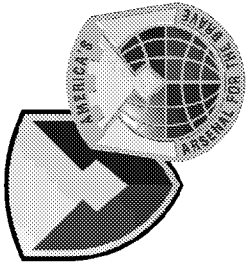
Life Cycle Test for commercial 1.4 AH Polymer Cell



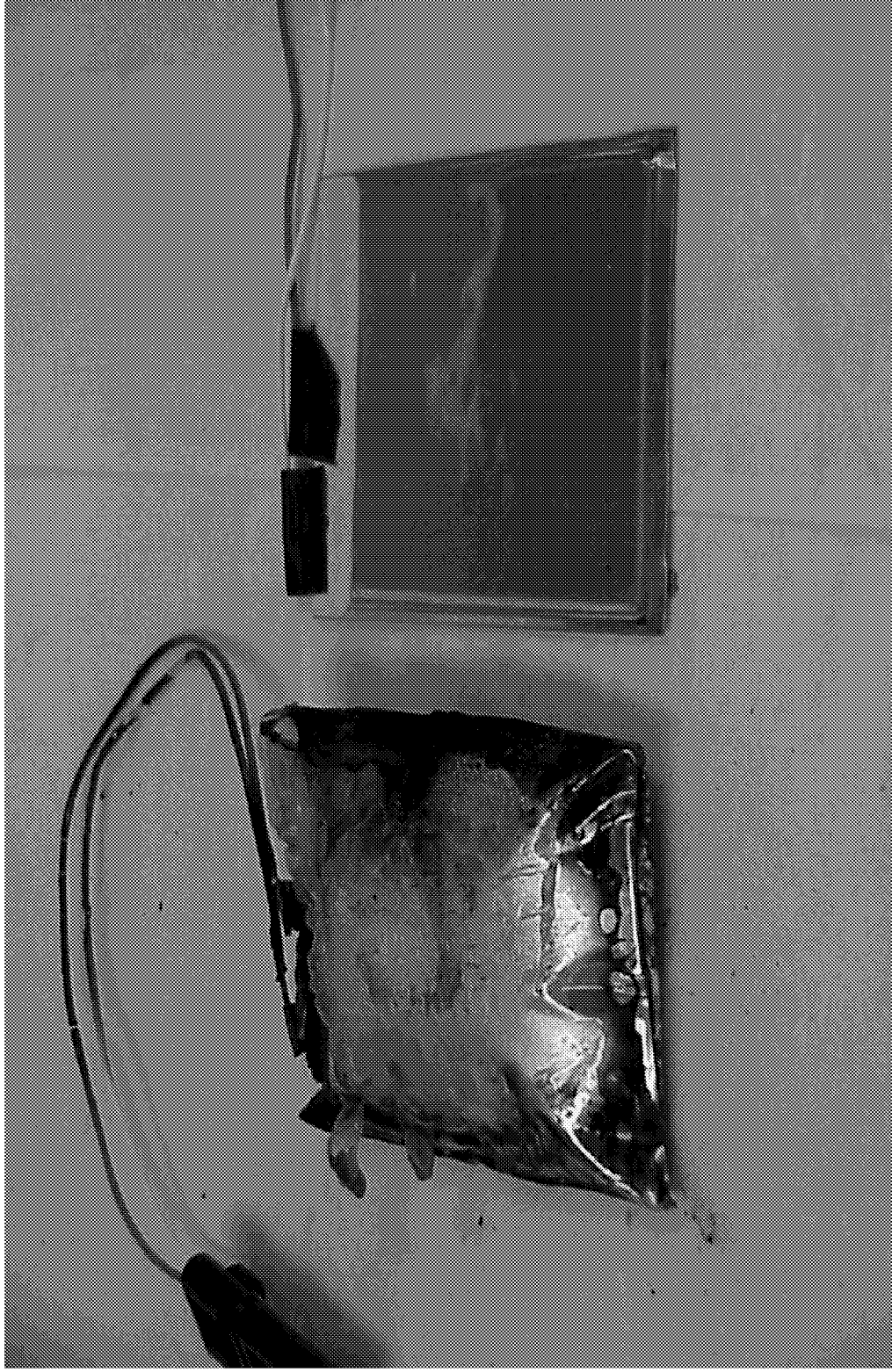
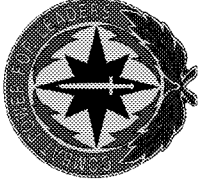
Polymer Cell 1.4 AH Life cycle test
Charge at 1.4A/4.2V,
discharge at .7A/2.75V



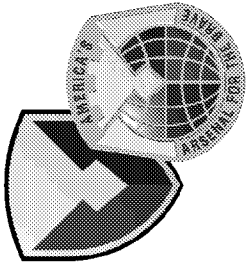
CECOM Bottom Line: THE SOLDIER



Burned 1.4 AH Polymer Lithium ion Cell During Cycling



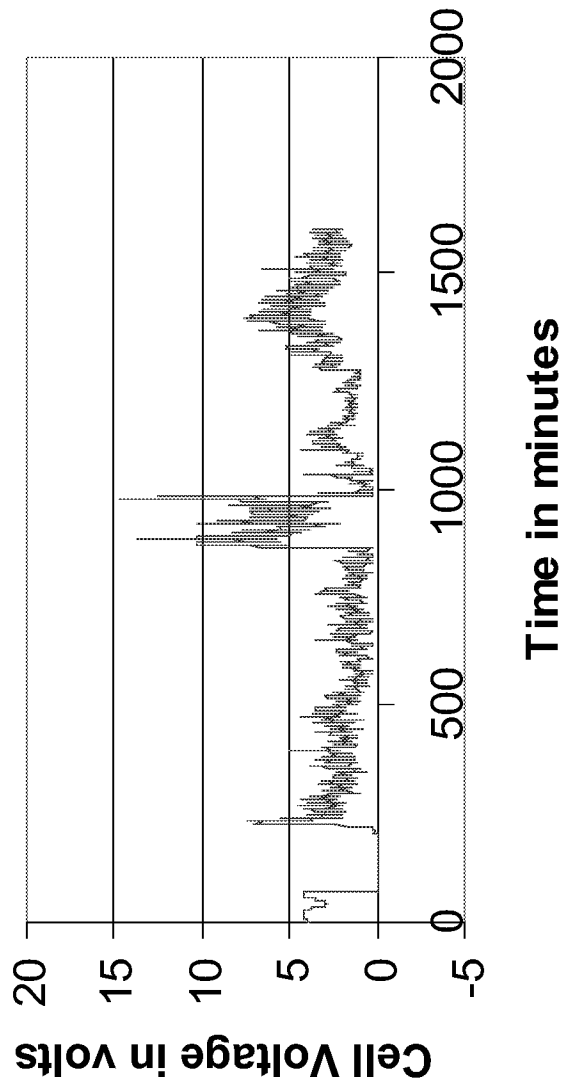
CECOM Bottom Line: THE SOLDIER



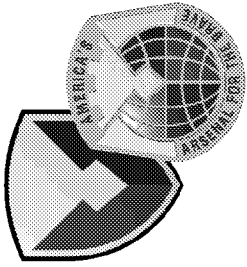
Shorted Polymer Lithium ion Cell During Cycling From 231 to 238



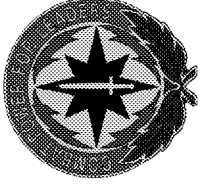
**Polymer Lithium ion 1.4 AH Cell
Charge at 1.4/4.2V/.05A, Discharge at
.7A/2.75V**



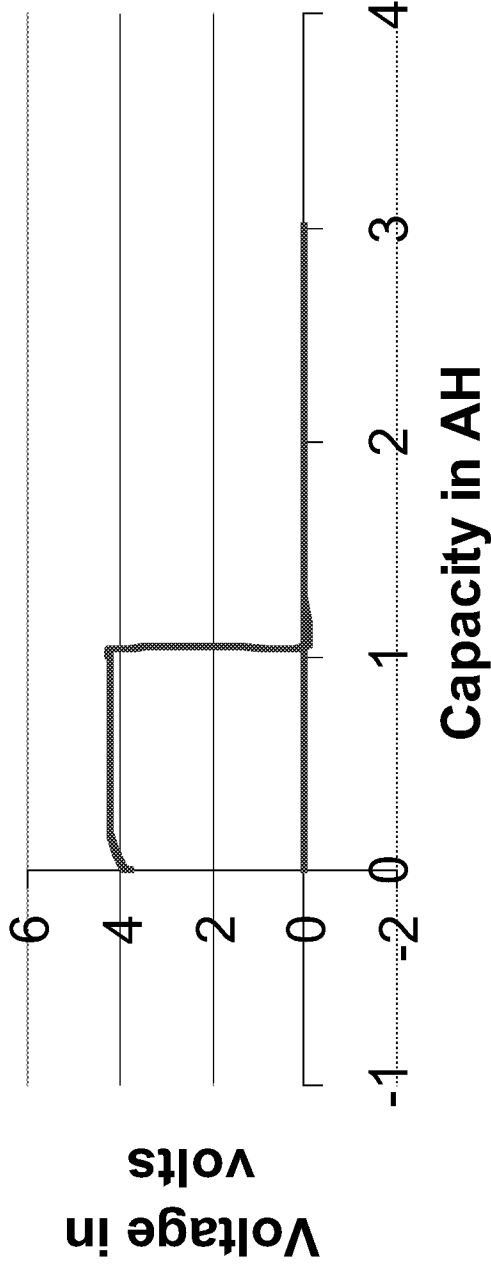
CECOM Bottom Line: THE SOLDIER

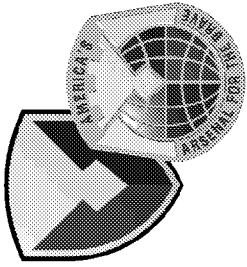


Shorted 1.4 AH Polymer Lithium ion Cell During Cycling

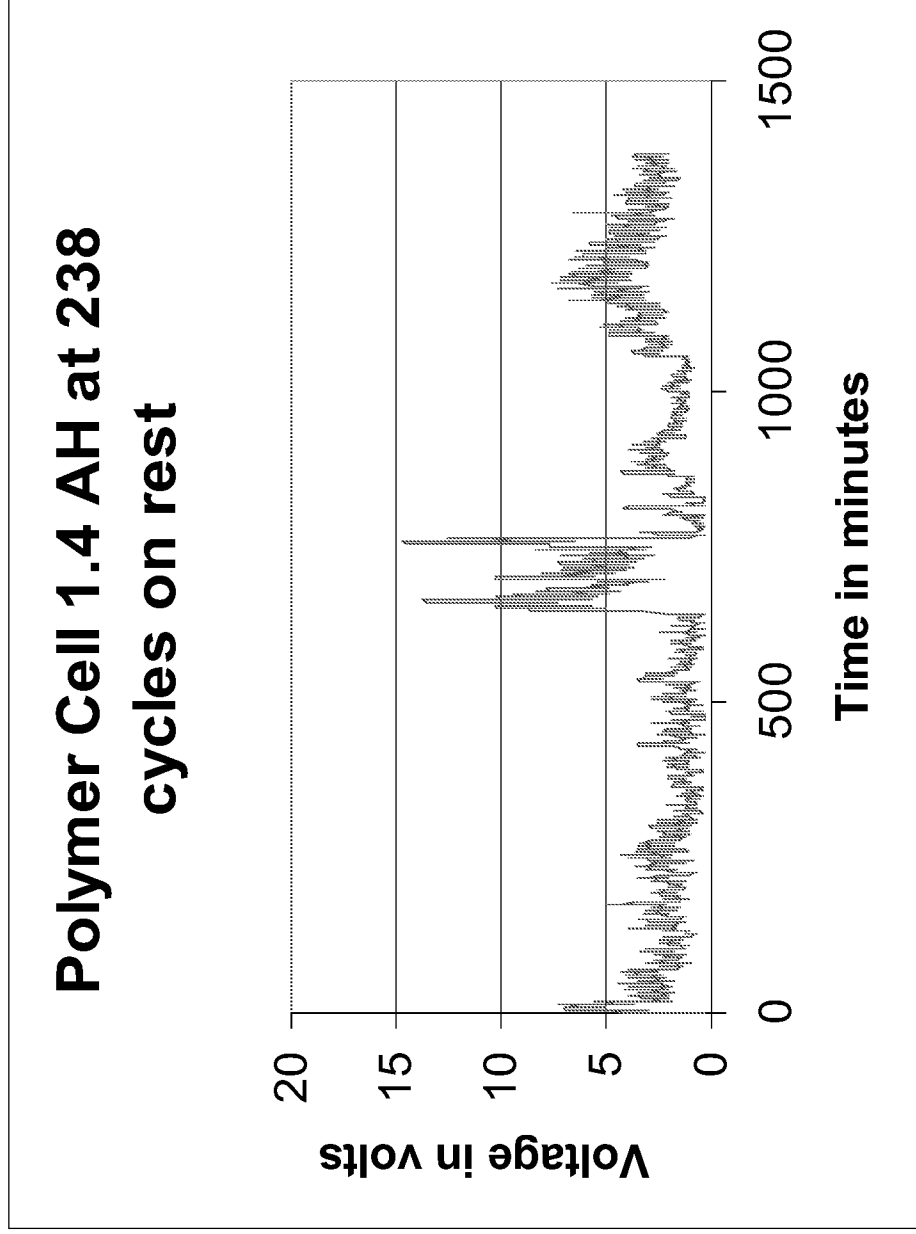
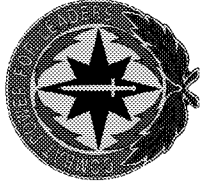


**Polymer Cell 1.4 AH 231 cycles
charge at 1.4 A to 4.2V Discharge
at .7A/2.75V**

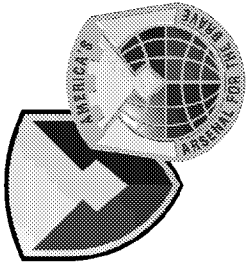




Shorted Polymer Lithium ion Cell During Cycling



CECOM Bottom Line: THE SOLDIER



Polymer Lithium ion Cell Cycle Data



	AH	WH	A	V
12318	231	4 62d 16:4	0d 01:00	0 3.57116 R
12319	231	5 62d 16:4	0d 00:00 6.23E-05	0.000233 1.399863 3.78265 C
12320	231	5 62d 16:47	0d 00:00 0.007572	0.029184 1.400015 3.882628 C
12321	231	5 62d 16:4	0d 00:01 0.034713	0.136102 1.400015 3.983154 C
12322	231	5 62d 16:50	0d 00:03 0.088652	0.353757 1.399939 4.083131 C
12323	231	5 62d 16:54	0d 00:07 0.170985	0.694314 1.399939 4.183108 C
12324	231	5 62d 17:04	0d 00:17 0.373095	1.542775 1.067292 4.199588 C
12325	231	5 62d 17:14	0d 00:27 0.532285	2.21114 0.872969 4.200137 C
12326	231	5 62d 17:24	0d 00:37 0.664404	2.765814 0.701534 4.200137 C
12327	231	5 62d 17:34	0d 00:47 0.771445	3.215159 0.588388 4.200137 C
12328	231	5 62d 17:44	0d 00:57 0.858548	3.580753 0.468299 4.199588 C
12329	231	5 62d 17:54	0d 01:07 0.929777	3.879686 0.379568 4.200137 C
12330	231	5 62d 18:04	0d 01:17 0.986491	4.117654 0.310979 4.200137 C
12331	231	5 62d 18:14	0d 01:27 1.032339	4.309986 0.243534 4.199588 C
12332	231	5 62d 18:1	0d 01:29 1.042173	4.351228 0.268788 1.900114 C
12333	231	5 62d 18:1	0d 01:29 1.042175	4.351228 0.391012 0 C
12334	231	5 62d 18:2	0d 01:39 1.27551	4.351228 1.400015 0 C
12335	231	5 62d 18:3	0d 01:49 1.508846	4.351228 1.400015 0 C
12336	231	5 62d 18:4	0d 01:59 1.742182	4.351228 1.399939 0 C
12337	231	5 62d 18:5	0d 02:09 1.975518	4.351228 1.400015 0 C
12338	231	5 62d 19:0	0d 02:19 2.208854	4.351228 1.399939 0 C
12339	231	5 62d 19:1	0d 02:29 2.44219	4.351228 1.400015 0 C
12340	231	5 62d 19:2	0d 02:39 2.675526	4.351228 1.400015 0 C

CECOM Bottom Line: THE SOLDIER



Polymer Lithium ion Cell Cycle Data

			AH	WH	A	V		
12245	230	3	62d 08:36	0d 01:14	0.873924	3.171562	0.700008	3.356374
12261	230	4	62d 09:36	0d 00:31	0	0	0	3.535454
12262	230	4	62d 09:56	0d 00:51	0	0	0	3.560174
12269	230	5	62d 10:21	0d 00:17	0.375898	1.554214	1.038605	4.200137
12270	230	5	62d 10:31	0d 00:27	0.53513	2.222758	0.87686	4.200137
12271	230	5	62d 10:41	0d 00:37	0.666299	2.773442	0.701839	4.200137
12272	230	5	62d 10:51	0d 00:47	0.773657	3.224118	0.587701	4.200137
12273	230	5	62d 11:01	0d 00:57	0.860612	3.589092	0.467994	4.199588
12274	230	5	62d 11:11	0d 01:07	0.931791	3.887816	0.385214	4.200137
12275	230	5	62d 11:21	0d 01:17	0.988114	4.124145	0.305257	4.200137
12276	230	5	62d 11:31	0d 01:27	1.034228	4.3176	0.244984	4.200137
12277	230	5	62d 11:41	0d 01:37	1.070484	4.469645	0.19791	4.200137
12278	230	5	62d 11:51	0d 01:47	1.100572	4.595777	0.159075	4.199588
12279	230	5	62d 12:01	0d 01:57	1.124518	4.696127	0.13344	4.199588
12280	230	5	62d 12:11	0d 02:07	1.144839	4.781248	0.105058	4.199588
12281	230	5	62d 12:21	0d 02:17	1.16137	4.85045	0.093462	4.199588
12282	230	5	62d 12:31	0d 02:27	1.175664	4.910261	0.072938	4.199588
12283	230	5	62d 12:41	0d 02:37	1.187588	4.960122	0.06836	4.200137
12284	230	5	62d 12:51	0d 02:47	1.197909	5.003245	0.052949	4.200137
12285	230	5	62d 13:01	0d 02:57	1.206755	5.040179	0.051499	4.200137
12288	230	6	62d 13:21	0d 00:20	0	0	0	4.171572
12289	230	6	62d 13:41	0d 00:40	0	0	0	4.165553
12295	231	3	62d 14:21	0d 00:24	0.289628	1.10583	0.700008	3.693111
12296	231	3	62d 14:31	0d 00:34	0.406296	1.532536	0.699931	3.62884
12297	231	3	62d 14:41	0d 00:44	0.522964	1.952393	0.699931	3.573358
12298	231	3	62d 14:51	0d 00:54	0.639632	2.366408	0.700008	3.527214
12299	231	3	62d 15:01	0d 01:04	0.7563	2.774047	0.700008	3.456901
12300	231	3	62d 15:11	0d 01:14	0.872968	3.172226	0.700008	3.371206
12316	231	4	62d 16:17	0d 00:30	0	0	0	3.539849
12317	231	4	62d 16:37	0d 00:50	0	0	0	3.564569
12324	231	5	62d 17:01	0d 00:17	0.373095	1.542775	1.067292	4.199588

CECOM Bottom Line: THE SOLDIER

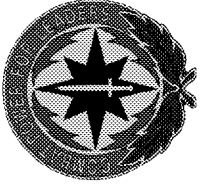


12374	233	4	63d 01:4€	0d 01:00	0	0	0	0	R
12375	233	5	63d 01:4€	0d 00:00	6.23E-05	0	1.400015	0	C
12376	233	5	63d 01:5€	0d 00:10	0.233398	0	1.399939	0	C
12377	233	5	63d 02:0€	0d 00:20	0.466734	0	1.400015	0	C
12378	233	5	63d 02:1€	0d 00:30	0.70007	0	1.400015	0	C
12379	233	5	63d 02:2€	0d 00:40	0.933406	0	1.399939	0	C
12380	233	5	63d 02:3€	0d 00:50	1.166742	0	1.400015	0	C
12381	233	5	63d 02:4€	0d 01:00	1.400078	0	1.399939	0	C
12382	233	5	63d 02:5€	0d 01:10	1.633413	0	1.400015	0	C
12383	233	5	63d 03:0€	0d 01:20	1.866749	0	1.400015	0	C
12384	233	5	63d 03:1€	0d 01:30	2.100085	0	1.399939	0	C
12385	233	5	63d 03:2€	0d 01:40	2.333421	0	1.399939	0	C
12386	233	5	63d 03:3€	0d 01:50	2.566757	0	1.400015	0	C
12387	233	5	63d 03:4€	0d 02:00	2.800093	0	1.399939	0	C
12388	233	5	63d 03:5€	0d 02:08	3.000003	0	1.399939	0	C
12389	233	6	63d 03:5€	0d 00:00	0	0	0	0	R
12390	233	6	63d 04:1€	0d 00:20	0	0	0	0	R
12391	233	6	63d 04:3€	0d 00:40	0	0	0	0	R
12392	233	6	63d 04:5€	0d 01:00	0	0	0	0	R
12393	234	3	63d 04:5€	0d 00:00	0	0	0	0	D
12394	234	4	63d 04:5€	0d 00:00	0	0	0	0	R
12395	234	4	63d 05:1€	0d 00:20	0	0	0	0	R
12396	234	4	63d 05:3€	0d 00:40	0	0	0	0	R
12397	234	4	63d 05:5€	0d 01:00	0	0	0	0	R
12398	234	5	63d 05:5€	0d 00:00	6.23E-05	0	1.399939	0	C
12399	234	5	63d 06:0€	0d 00:10	0.233398	0	1.400015	0	C
12400	234	5	63d 06:1€	0d 00:20	0.466734	0	1.399939	0	C
12401	234	5	63d 06:2€	0d 00:30	0.70007	0	1.399939	0	C
12402	234	5	63d 06:3€	0d 00:40	0.933406	0	1.399939	0	C
12403	234	5	63d 06:4€	0d 00:50	1.166742	0	1.399939	0	C
12404	234	5	63d 06:5€	0d 01:00	1.400078	0	1.400015	0	C
12405	234	5	63d 07:0€	0d 01:10	1.633413	0	1.399939	0	C
12406	234	5	63d 07:1€	0d 01:20	1.866749	0	1.399939	0	C
12407	234	5	63d 07:2€	0d 01:30	2.100085	0	1.400015	0	C
12408	234	5	63d 07:3€	0d 01:40	2.333421	0	1.400015	0	C
12409	234	5	63d 07:4€	0d 01:50	2.566757	0	1.399939	0	C
12410	234	5	63d 07:5€	0d 02:00	2.800093	0	1.400015	0	C
12411	234	5	63d 08:0€	0d 02:08	3.000003	0	1.400015	0	C
12412	234	6	63d 08:0€	0d 00:00	0	0	0	0	R

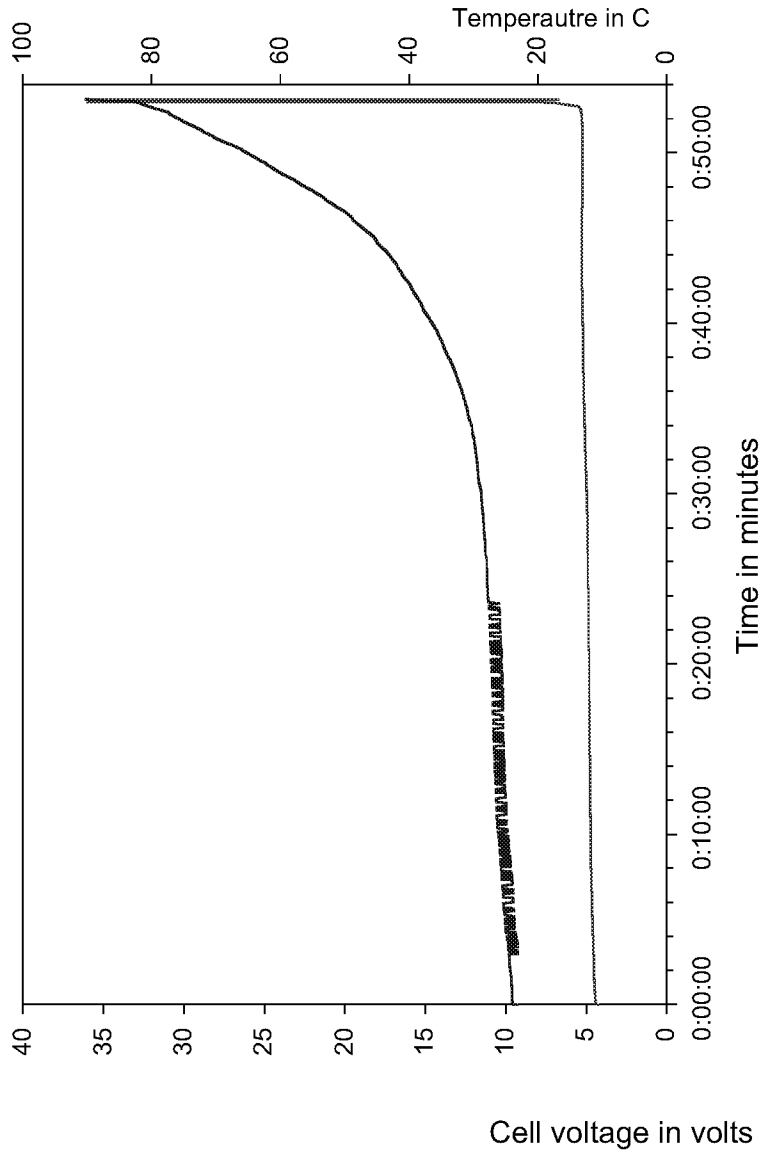
CECOM Bottom Line: THE SOLDIER



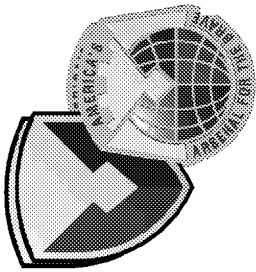
Overcharge Tests for Commercial 18650



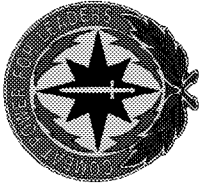
18650 Cell Overcharge test
Charge at 1.35 A



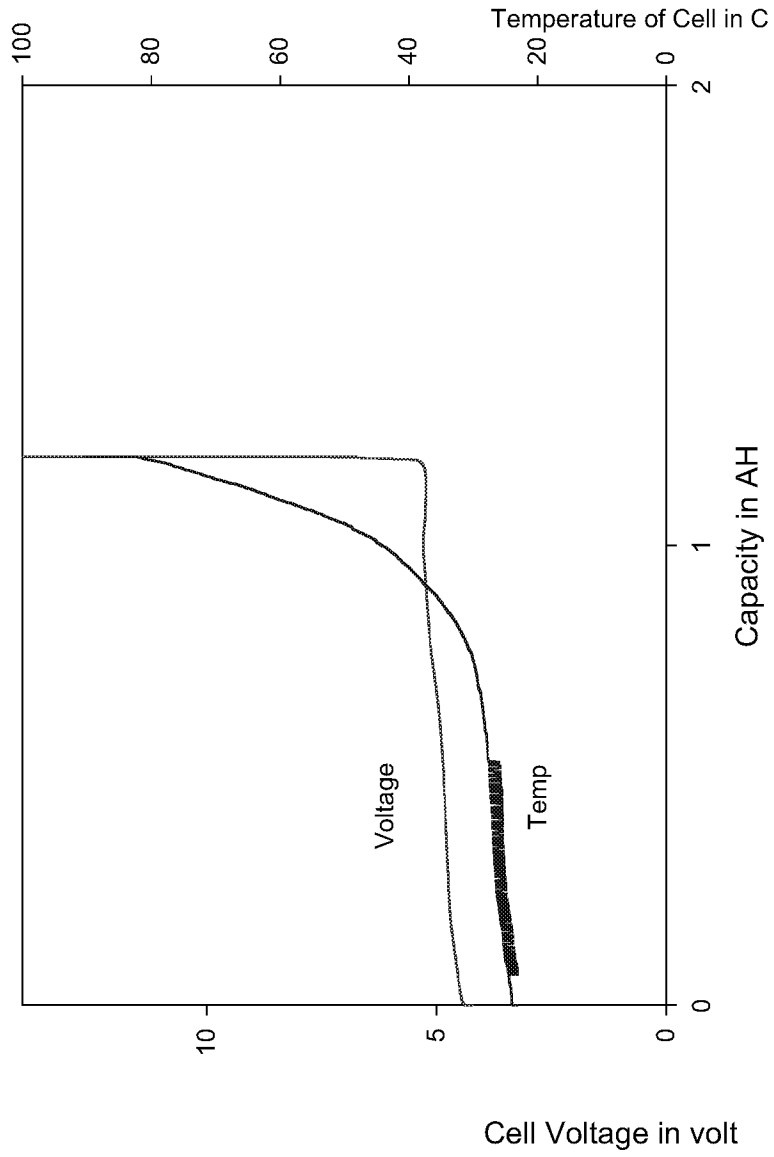
CECOM Bottom Line: THE SOLDIER



Overcharge Tests for Commercial 18650



18650 Cell Overcharge Test
Constant current charge at 1.35 A



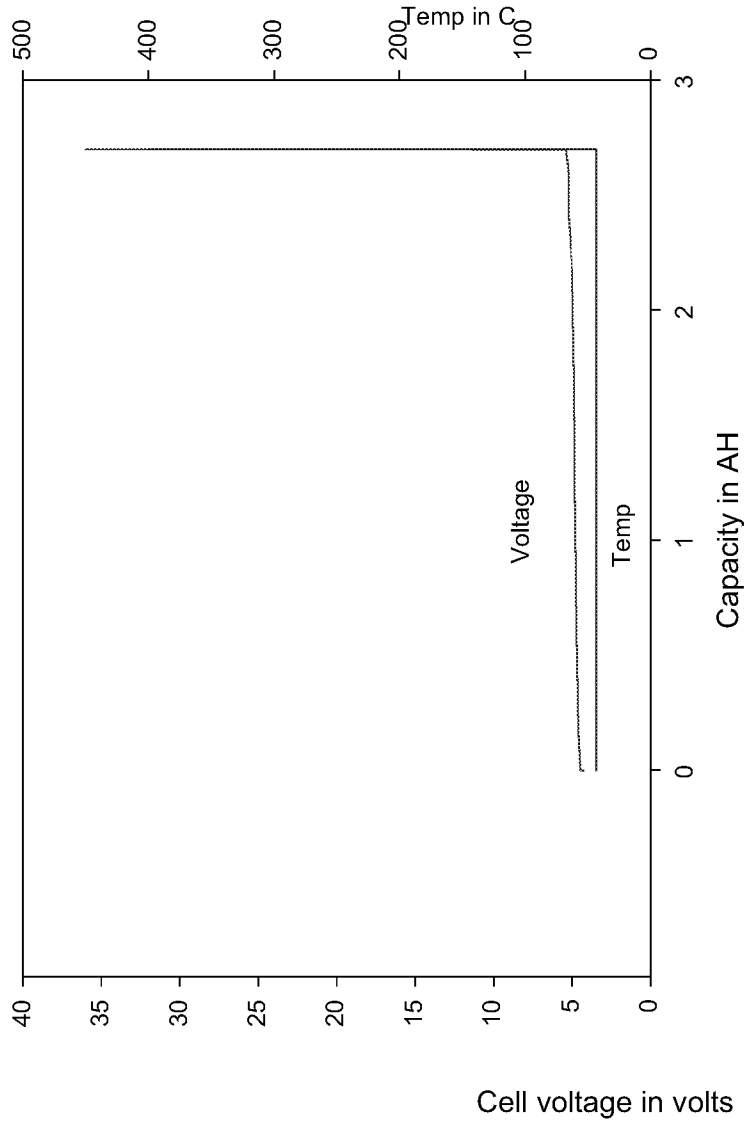
CECOM Bottom Line: THE SOLDIER



Overcharge Test for Commercial 26650



Lithium ion Cell 26650 overcharge tests
Constant at 2.5 Amps



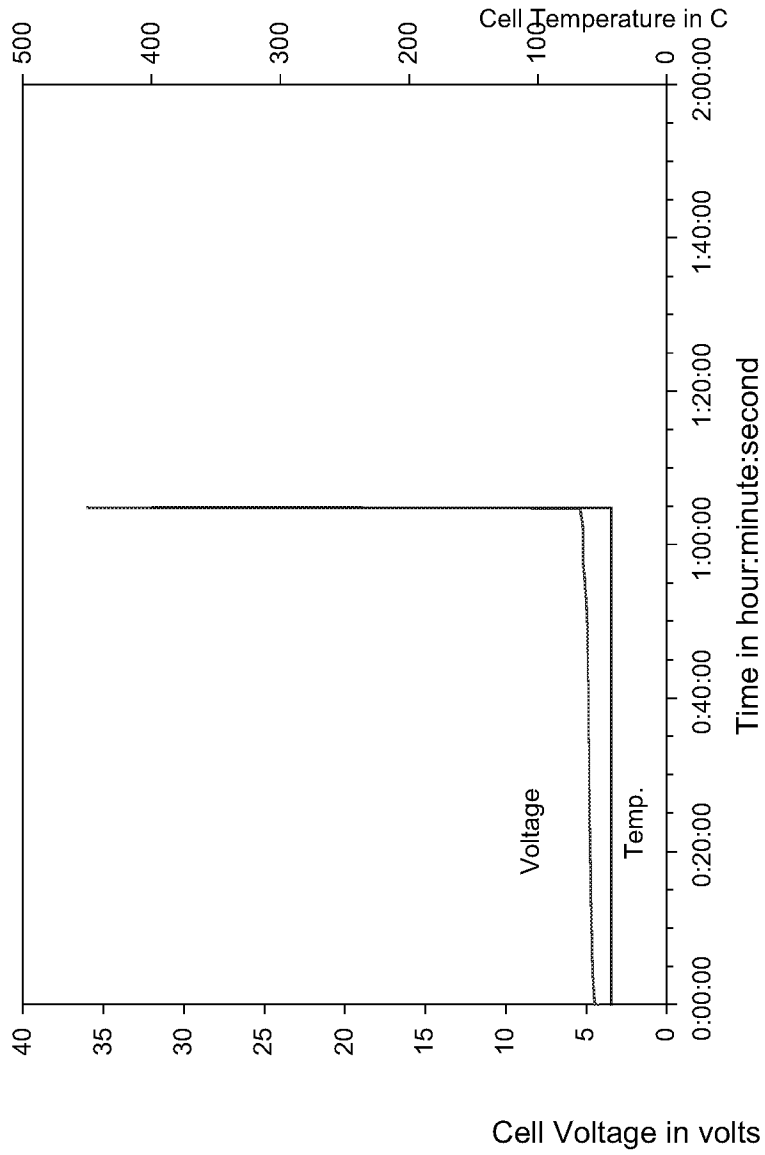
CECOM Bottom Line: THE SOLDIER



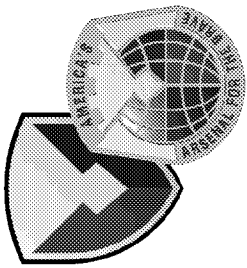
Overcharge Test for Commercial 26650



Lithium ion Cell 26650 Overcharge tests
Constant Current Charge at 2.5 amperes



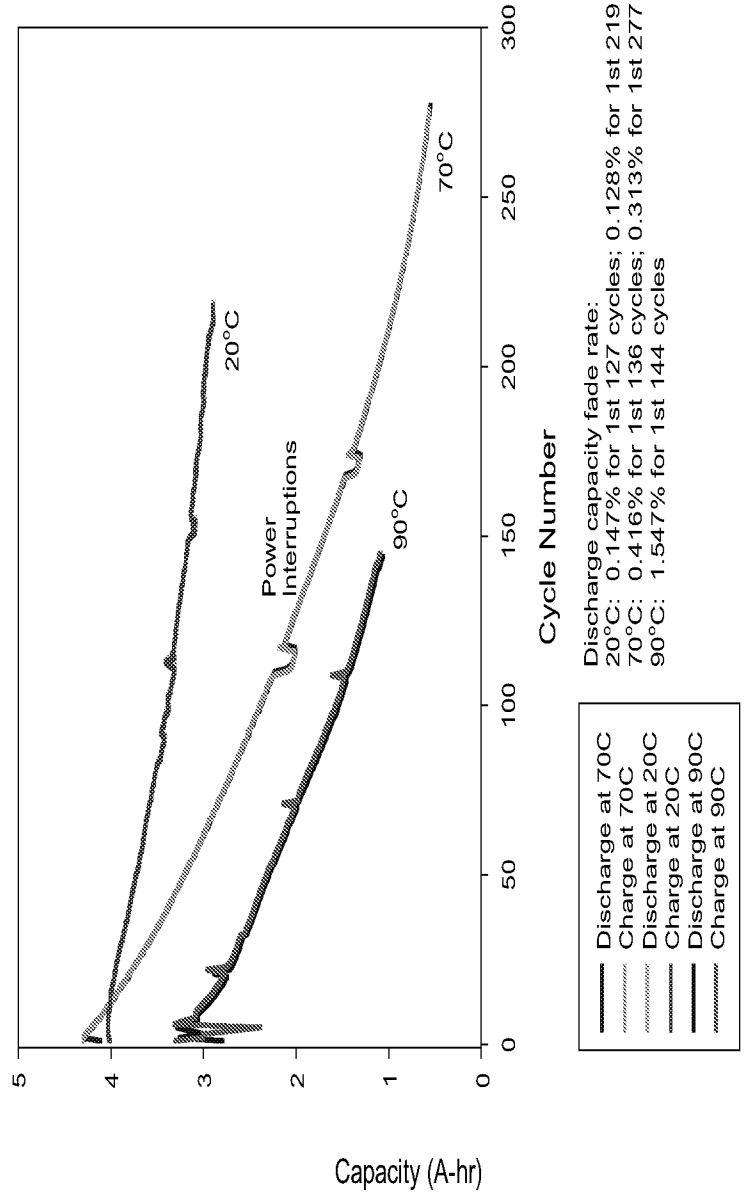
CECOM Bottom Line: THE SOLDIER

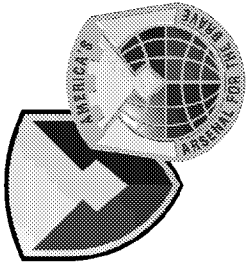


Lithium ion D cell cycling at 20 C, 70 C, and 90 C



Fig 9: 34570 (D) cell #20, #18, and #21 w/1.0M LiPF₆ 1EC:1DMC:1EMC
Discharge 2A / Charge 4A
#20 at 70°C, #18 at 20°C, #21 at 90°C
Lifecycle Test

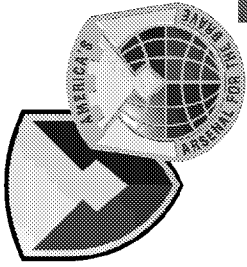




Overcharge Test Lithium ion D Cell with Rupture disk and Electrolyte Started to Leak out



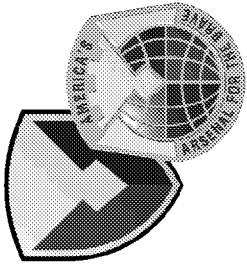
CECOM Bottom Line: THE SOLDIER



Overcharge Test D cell Spark Come out of Rupture vent



CECOM Bottom Line: THE SOLDIER



Overcharge Test D cell, Voltage went to Zero
and Temperature rise to 256 C



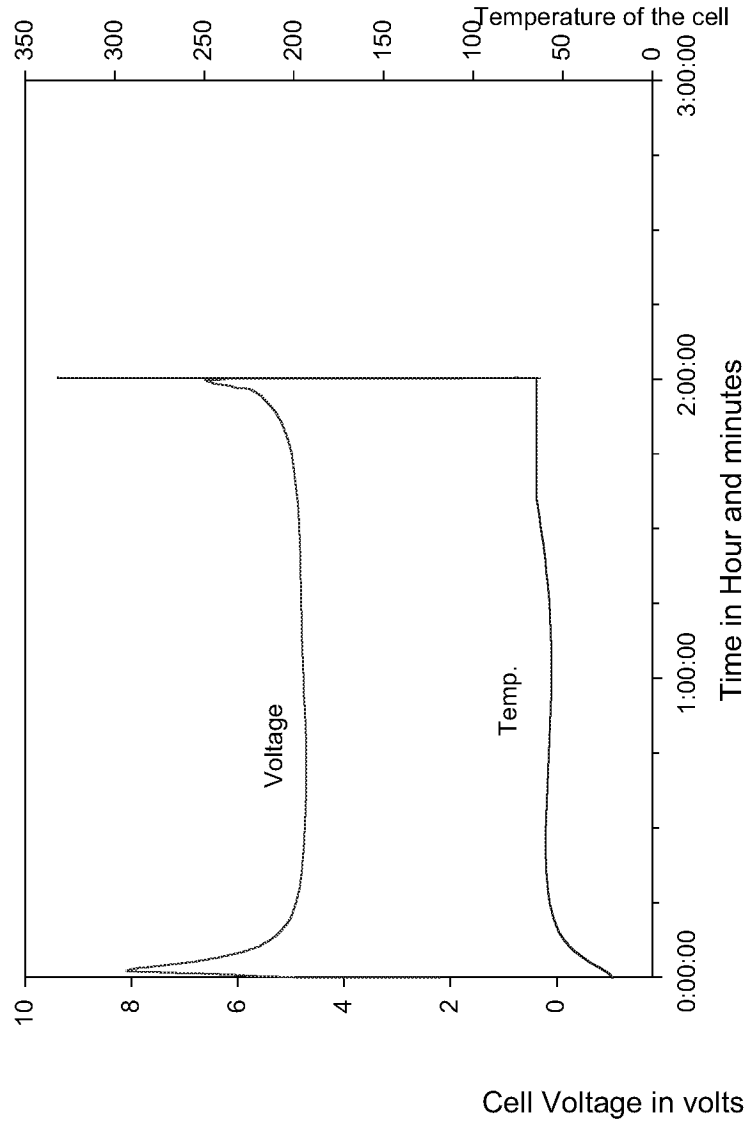
CECOM Bottom Line: THE SOLDIER



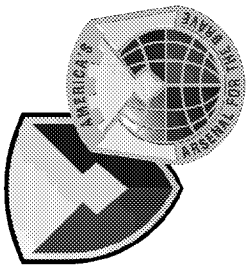
Overcharge Test Lithium ion “D” Size



Lithium ion D size cell
charge at 4 A



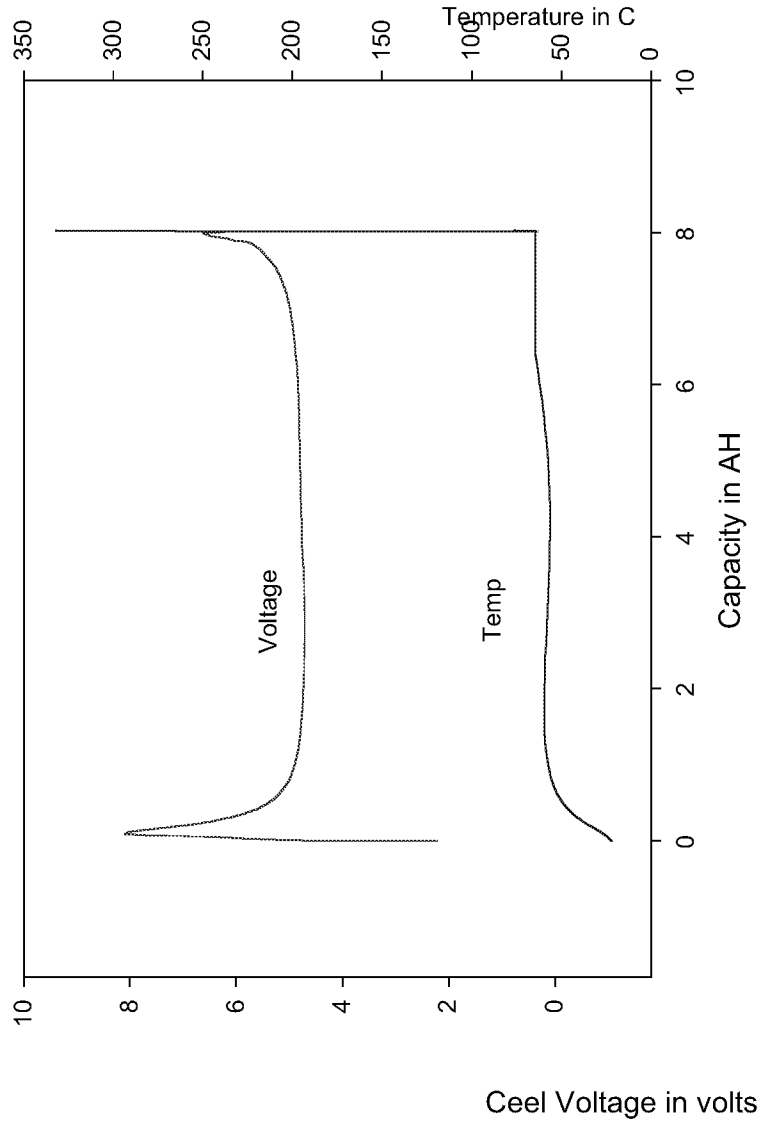
CECOM Bottom Line: THE SOLDIER



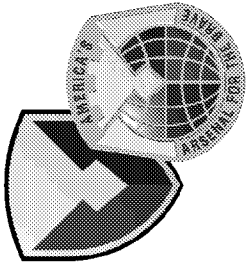
Overcharge Test Lithium ion "D" Size



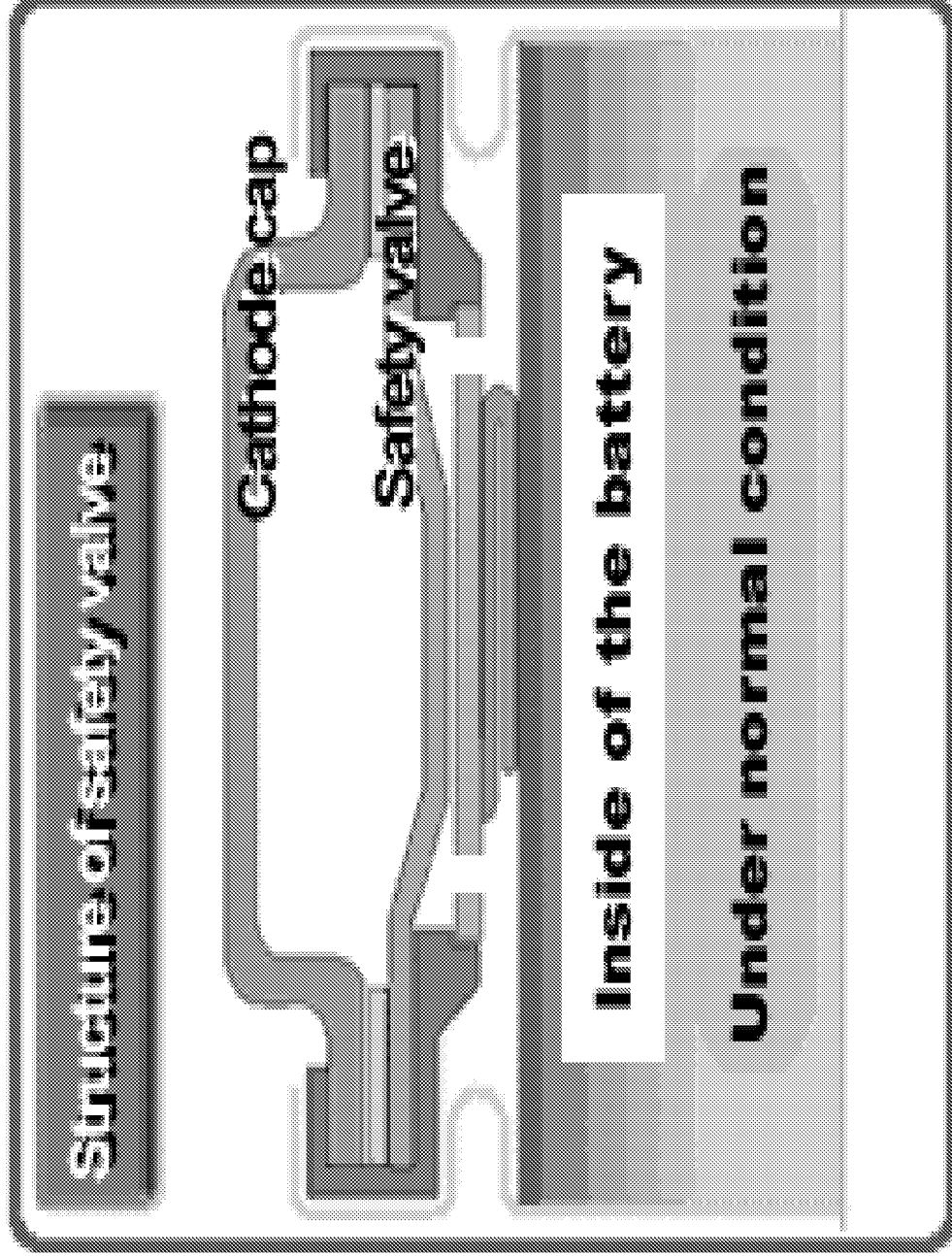
Lithium ion D size Cell Overcharge charge tests
Charge at constant current at 4.0A



CECOM Bottom Line: THE SOLDIER

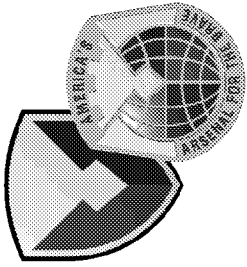


Commercial 18650 Pressure Disconnect Vent

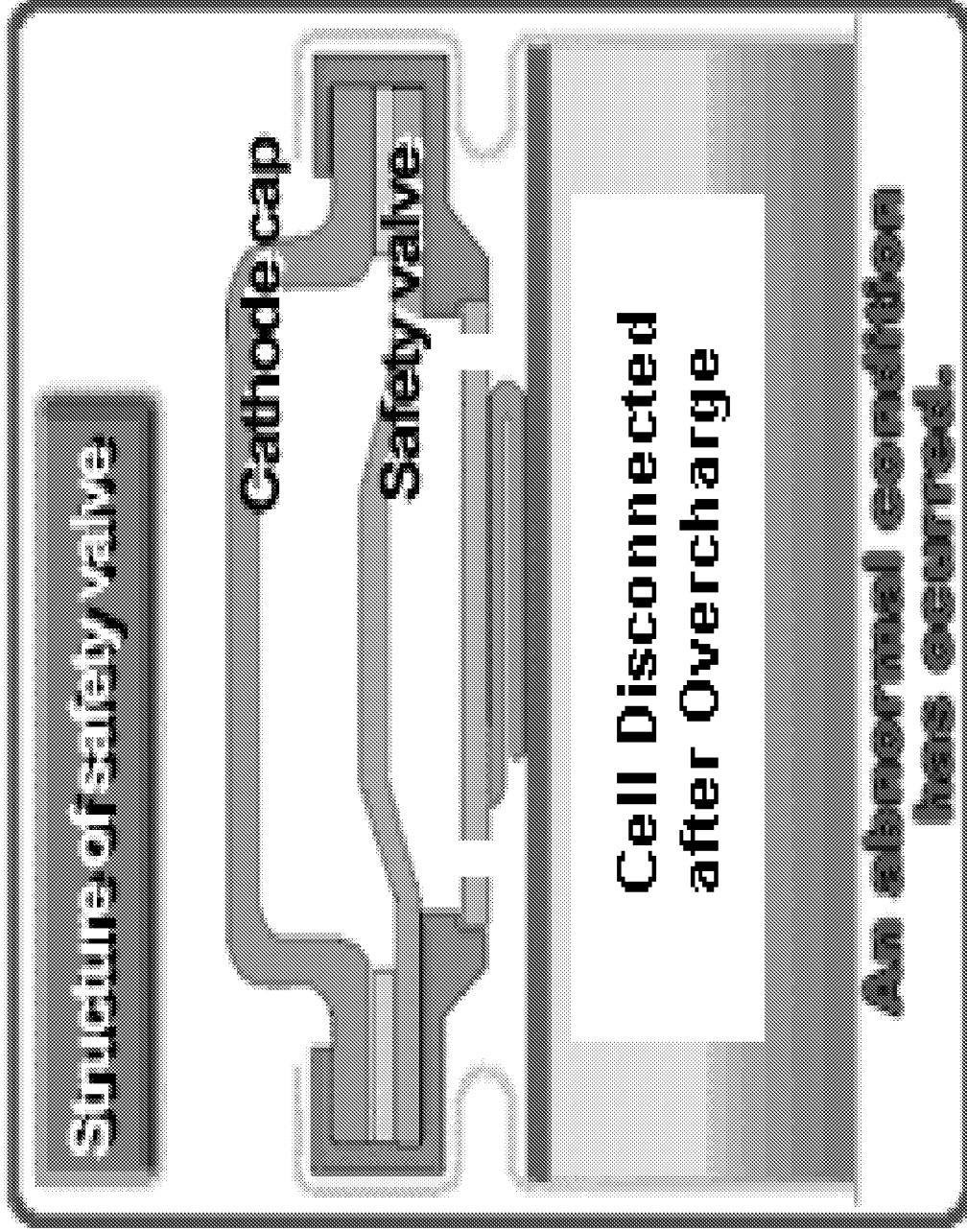


From M.Reid, E-One Moli Energy Limited

CECOM Bottom Line: THE SOLDIER

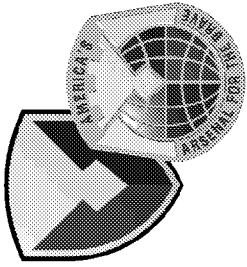


Commercial 18650 Pressure Disconnect Vent

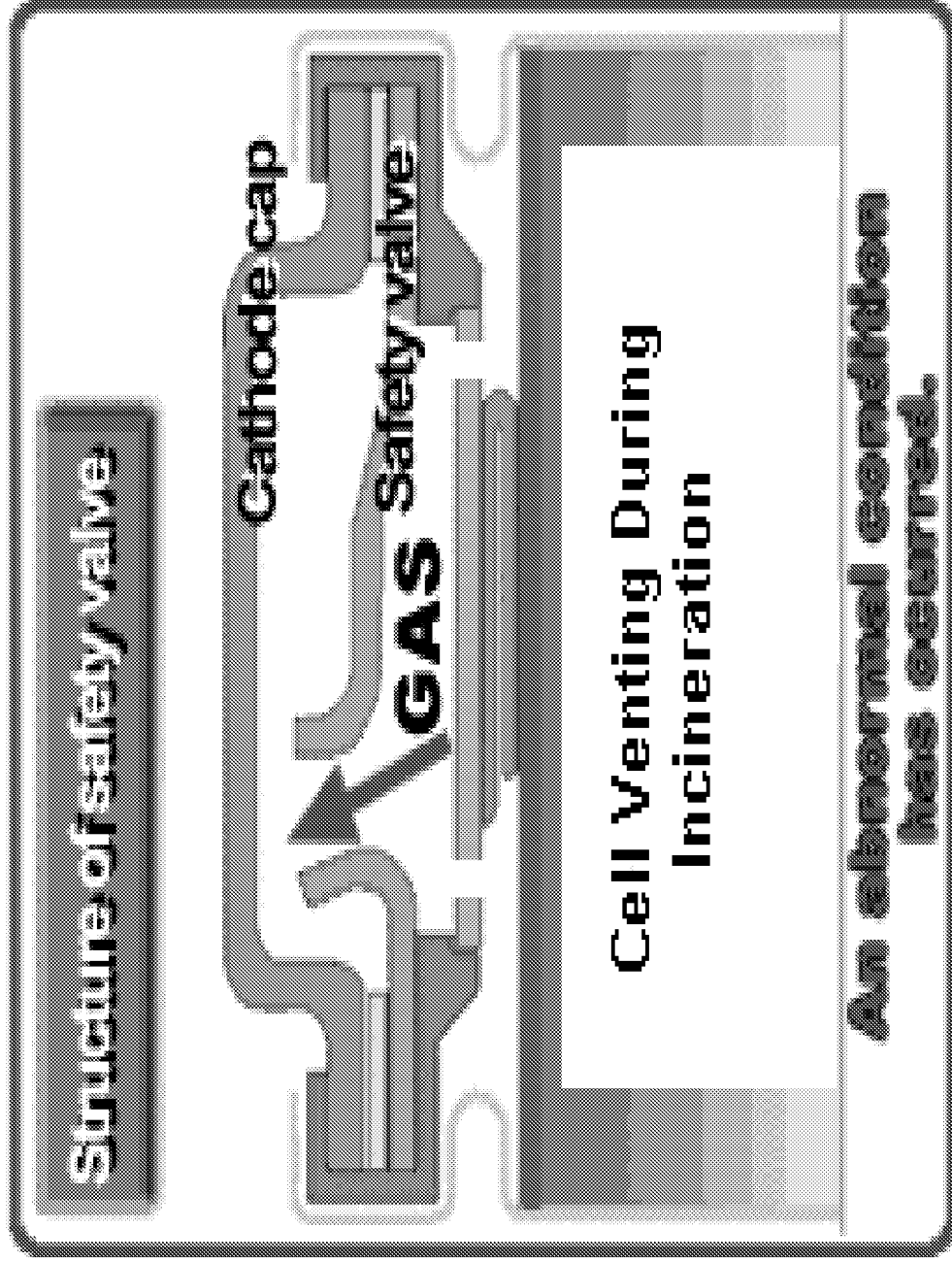


From M.Reid, E-One Moli Energy Limited

CECOM Bottom Line: THE SOLDIER

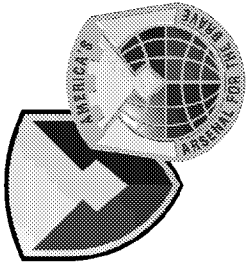


Commercial 18650 Pressure Disconnect Vent

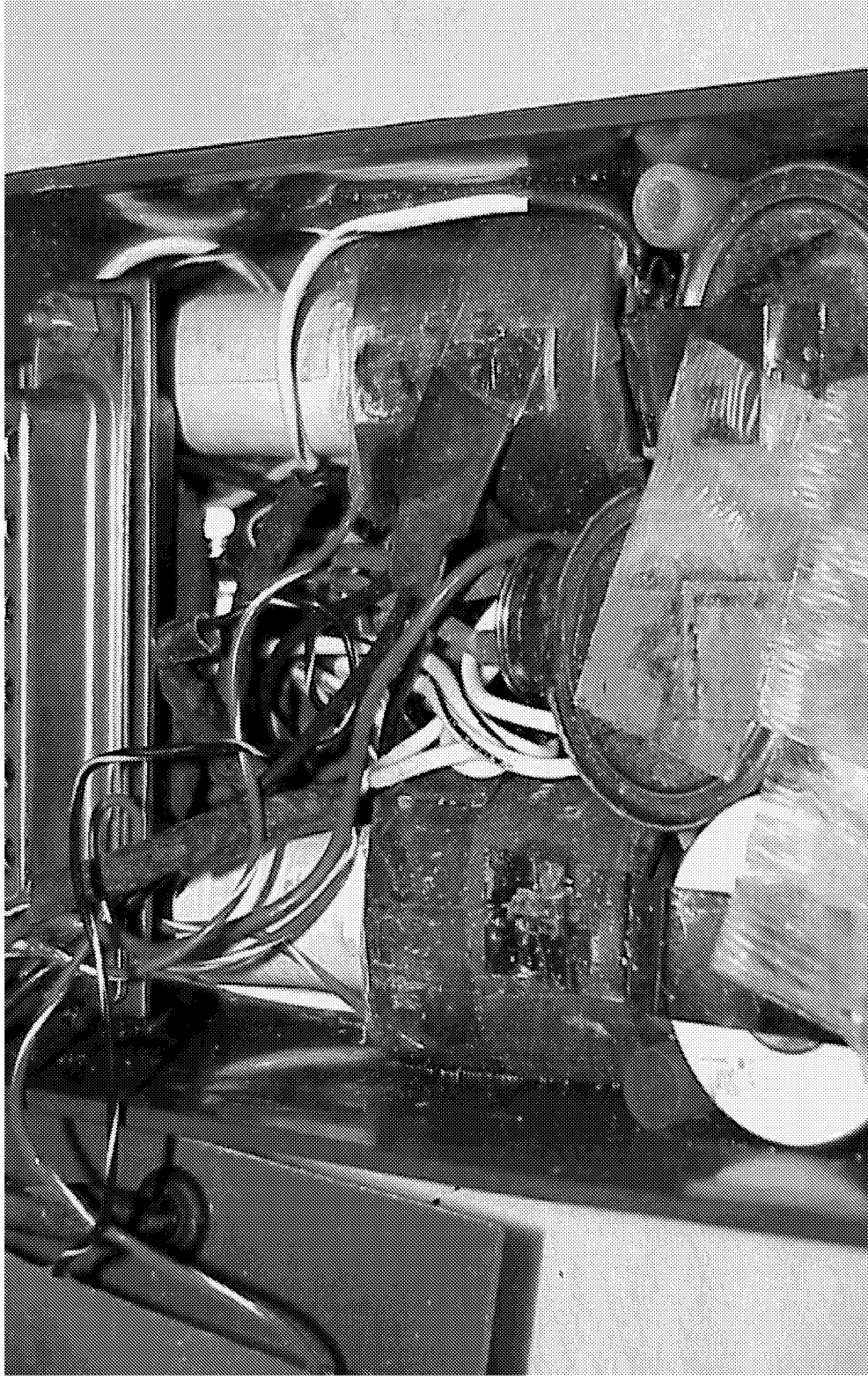


From M.Reid, E-One Moli Energy Limited

CECOM Bottom Line: THE SOLDIER



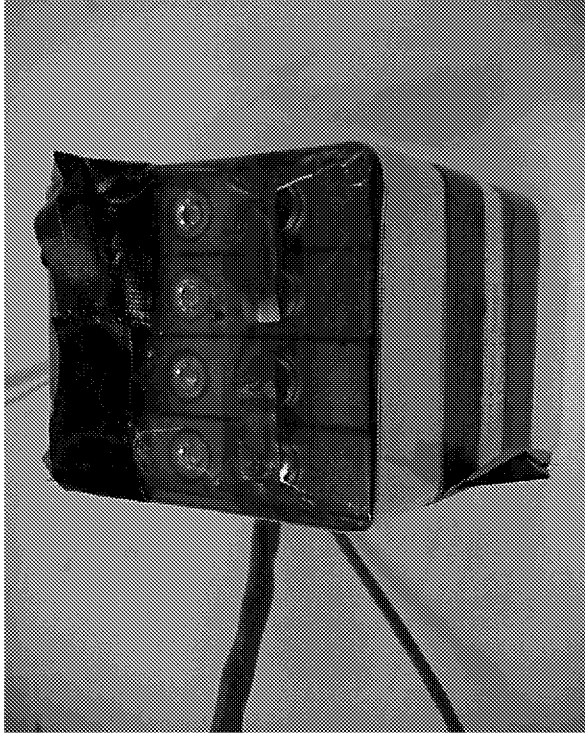
Nicad BB-542/U using Pressure Switch for Fast Charge Termination or Cutoff



CECOM Bottom Line: THE SOLDIER



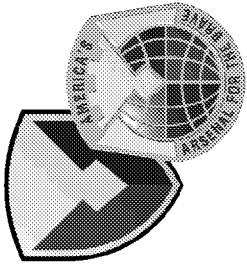
Large Lithium ion Cell and Batteries using the rupture disk



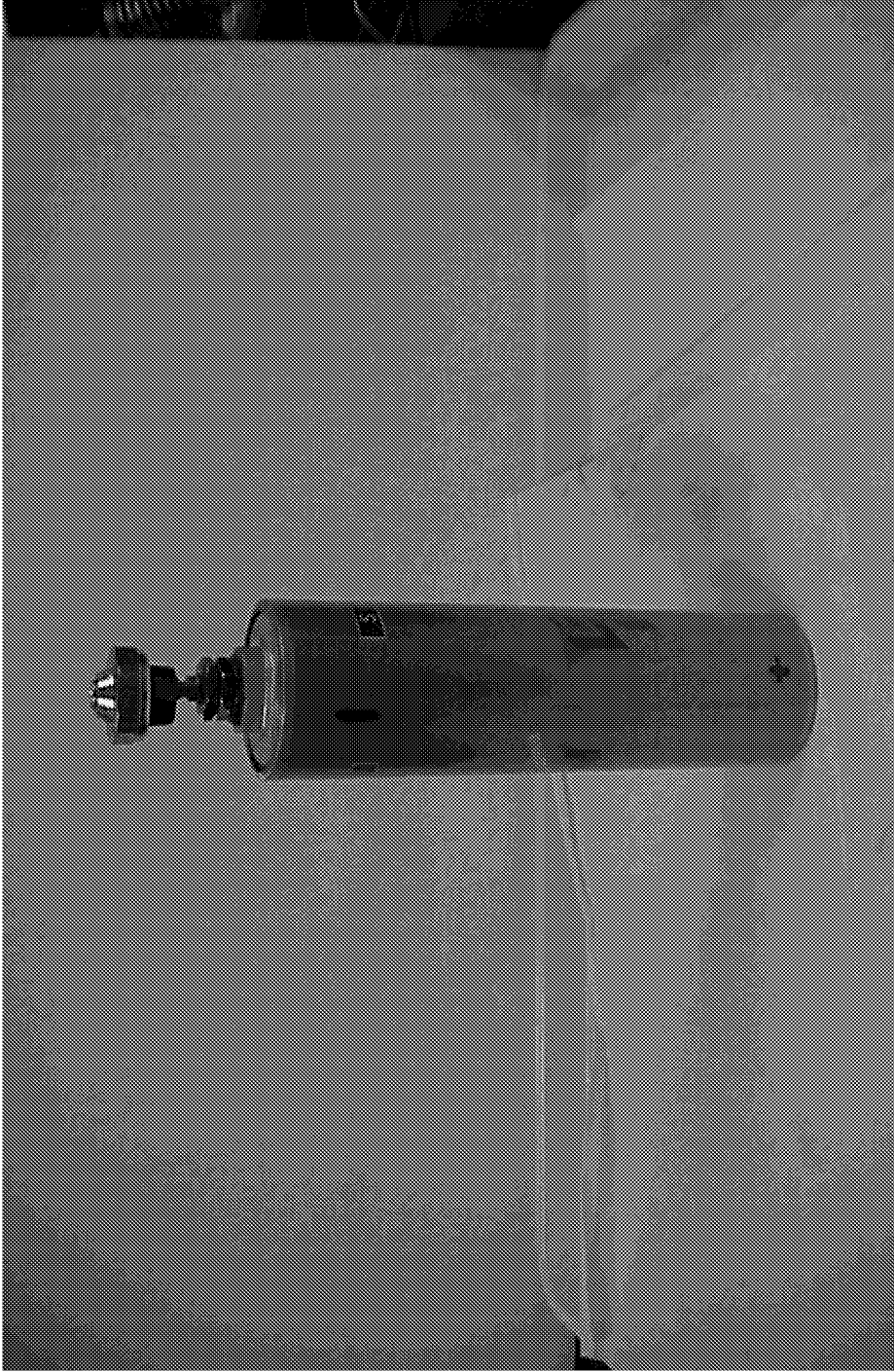
20 AH, 14.4 V Battery



40 AH, Single Cell



Propose Mechanical Pressure Switch for a large Lithium ion Cell



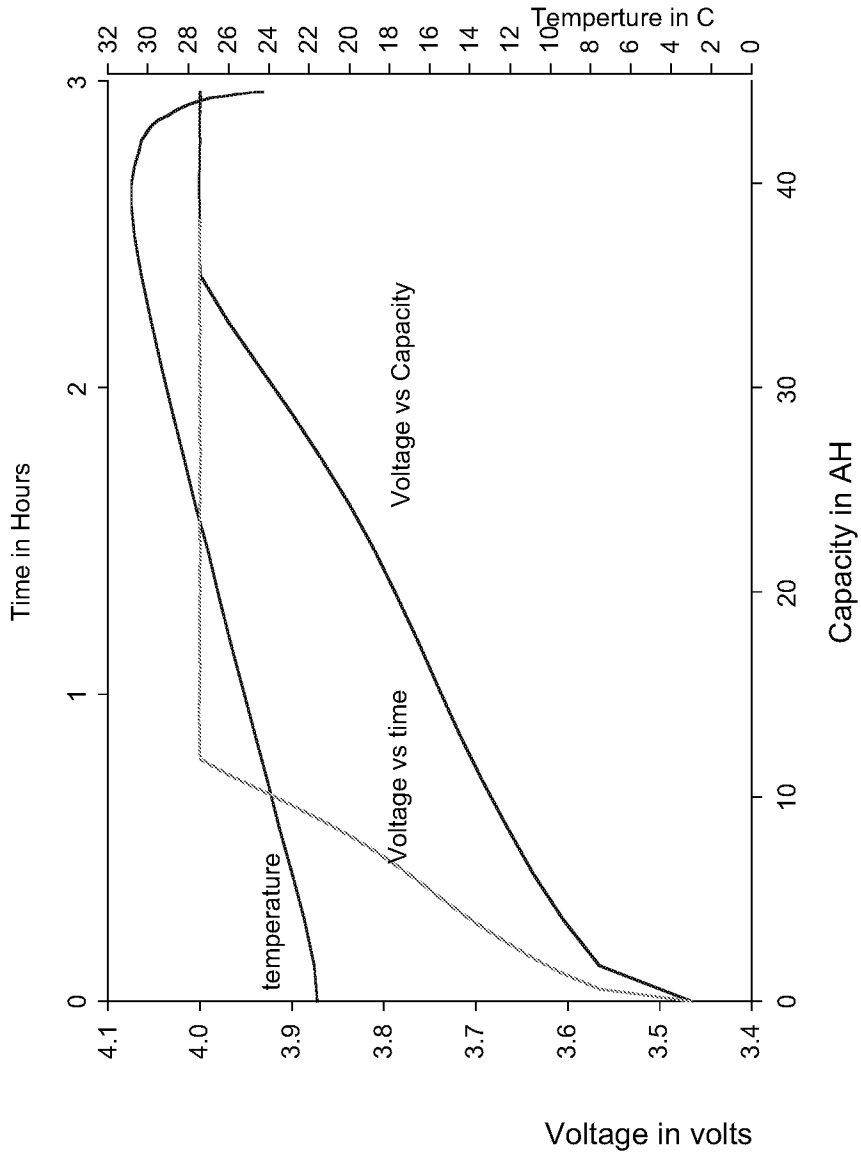
CECOM Bottom Line: THE SOLDIER



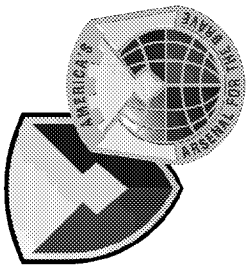
40 AH Cell Charge at C rate to 4.0V



40 AH Cell Charge at 45A/4.0V/0.01A



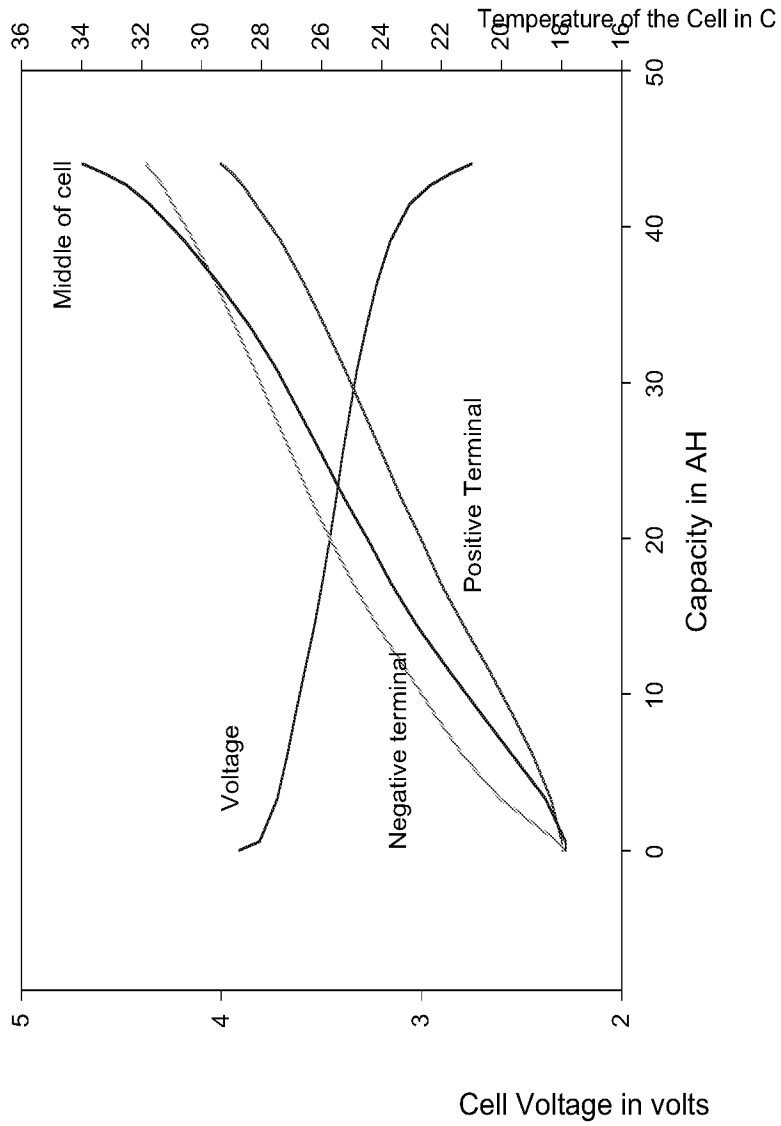
CECOM Bottom Line: THE SOLDIER



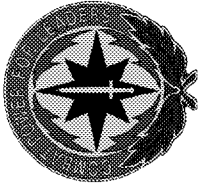
40 AH Lithium ion Cylindrical Cell Discharge at 55 Amperes to 2.75V Cutoff



Lithium ion Cell 40AH, Discharge at 55A to 2.75V at 18 C

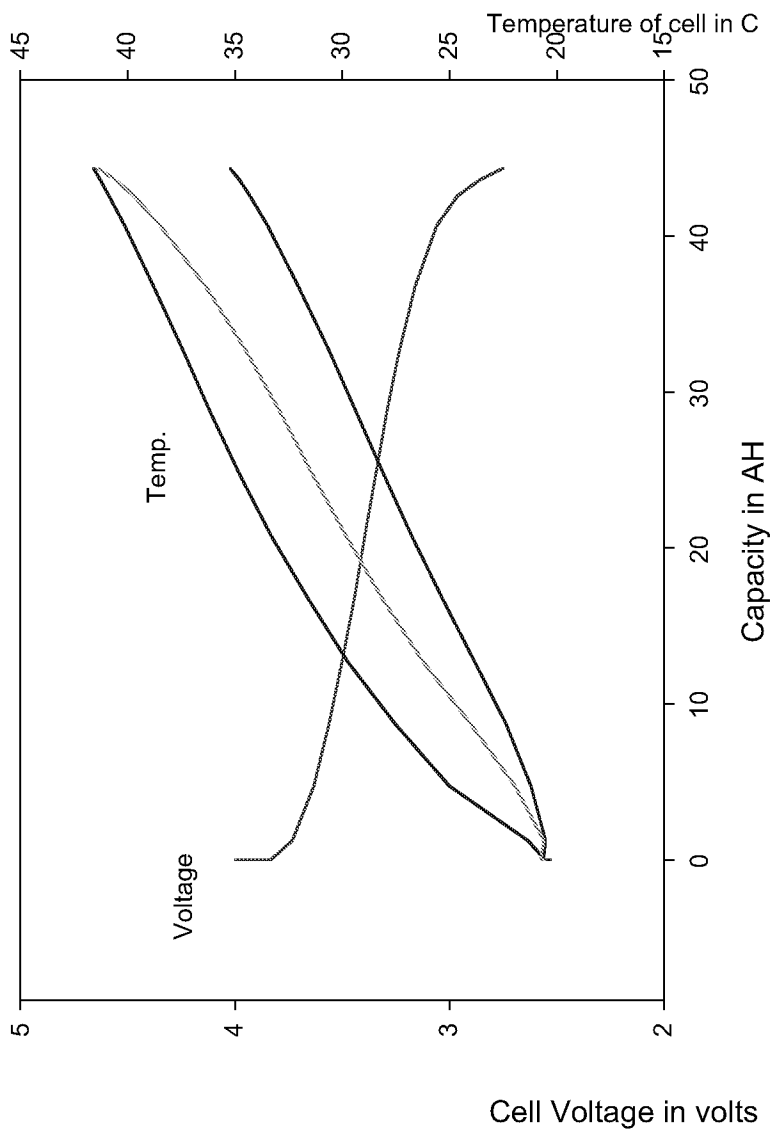


CECOM Bottom Line: THE SOLDIER

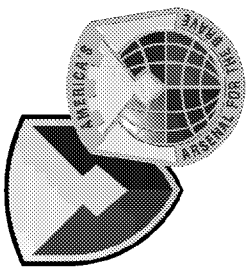


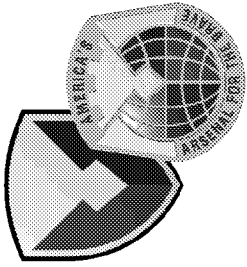
40 AH Cell Discharge at 2C

40 AH Cell Discharge at 80A



CECOM Bottom Line: THE SOLDIER



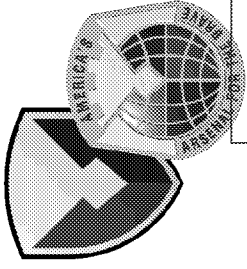


Propose Cell Specification For a Large Lithium ion Cell



- 3.5.3 Cell safety A single cell that does not contain any electronics shall meet all the safety requirement listed below:
- 3.5.3.1 Cell overcharge. After being subjected to the test as specified in 4.4.2.3.1 the cell shall not explode or catch fire or spark. No electrodes or separator material of the cell shall be outside of the cell case.
- 3.5.3.2 Cell short circuit. After being subjected to the test as specified in 4.4.2.3.2 the cell shall not explode or catch fire.
- 3.5.3.3 Cell Forced-Discharge. After a single cell in the string has been subjected to the test as specified in paragraph 4.4.2.3.3 , there shall be no leaking, venting, fire or explosion.
- 4.4.2.3.1 Cell overcharge. A single cell shall be placed in a temperature chamber set at 25°C. A thermocouple shall attach to the side of the cell, and current carrying and voltage monitoring leads shall be attached to the terminals. A constant C/2 current charging rate shall be applied for 8 hours continuously. Cell temperature, voltage, and current shall be recorded. A single cell shall meet the requirement for 3.5.3.1.
- 4.4.2.3.2 Cell short circuit. A single cell shall be shorted by connecting the positive and negative terminals of the cell with a less than 8 inch in length of No. 0 AWG or equivalent copper wire. The cell shall be completely discharged and the battery case temperature has returned to near ambient temperature. The cell shall meet the requirement of 3.5.3.2.
- 4.4.2.3.3 Cell forced-discharge. A completely discharged single cell (less than 0.2 volts) is to be forced-discharge in accordance with method 2 of the forced-discharge test of UL-1642. One cell for each cell string shall be discharged at the rate specified (see 3.1) to a test end voltage of two-thirds of its open circuit voltage. It shall then be connected in series with the appropriate number of charged cells which shall then be discharged at the rate specified (see 3.1) to a test end voltage of the applicable specification sheet. All cells shall comply with requirements (see 3.5.3.3).

CECOM Bottom Line: THE SOLDIER



Conclusion and Recommendation for Lithium ion Cell & Battery Safety Design



Cell Level

- Shall have Pressure Switch for large Lithium ion Cell and Pressure Disconnect and /or PTC device for small lithium ion Cell. These Devices must capable to disrupt of current flow.

Battery Level

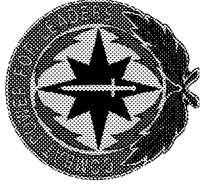
- Charge controller – Overvoltage and undervoltage, Temperature devices.

Charger Level

- Overvoltage, Undervoltage, overcharge, temperature termination.



Acknowledgements



DARPA, Technology Reinvestment Program

Saft America, Inc.

Yardney (Lithion) Inc.

E-One Moli Energy Limited

Maxell Inc.

NASA, Mars Exploration Program

JPL, California Institute of Technology

US Army, CECOM, Ft. Monmouth

US Airforce, Wright Paterson AFB

CECOM Bottom Line: THE SOLDIER