

Li-Ion Cell Lot Testing and Flight Screening Results

February 1, 2011

Justin H. Lee and John S. Halpine
Electronics and Photonics Laboratory
Physical Sciences Laboratories

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Space and Missile Systems Center
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245-2808

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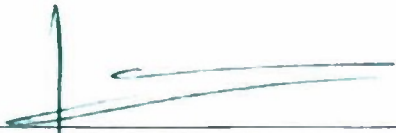
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Approved by:



Bernardo Jadaszliwer, Principal Director
Electronics and Photonics Laboratory
Physical Sciences Laboratories



James G. Gee, Principal Director
Developmental Planning and Projects
Corporate Chief Architect/Engineer Division
Systems Planning and Engineering

Abstract

This document reports the lot characterization and sample testing required for certification of a new lot of Moli-Energy Li-Ion ICR-18650H 2200-mAh, 3.75-V cells to be used for a future picosatellite (PicoSat) or CubeSat flight experiment. Results from the required screening of 100% of the flight cells that constitute this new lot are also presented. All testing began upon receipt of the new cell lot in March 2009 and was performed with the primary objective of flight certifying the cells according to NASA standards. The present document supersedes a previous document published in 2009 on a similar subject.¹

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1. Introduction

1.1 Purpose

This document reports the lot characterization and sample testing required for certification of a new lot of Moli-Energy Li-Ion ICR-18650H 2200 mAh, 3.75 V cells to be used for a future picosatellite (PicoSat) flight experiment. Results from the required baseline characterization of 100% of the new cell lot are also presented.

All testing began upon receipt of the new cell lot in March 2009 and was performed with the primary objective of flight certifying the cells according to NASA standards.

Similar cells were tested for the pathfinder PSSC Testbed, which achieved orbit in late November 2008; it completed its primary mission and ultimately lasted for about 3 months. Past lot screening results were published in a previous report.¹ The cells tested and presented in this report were manufactured at a different factory than that in the previous report. Otherwise, the cell specifications are identical.

The development of PicoSats and CubeSats at The Aerospace Corporation exists as an innovative, cost-friendly method for testing a constantly growing number of applications in space. Li-Ion cell testing for PicoSats and CubeSats includes basic physical and electrochemical characteristics measurements to ensure that the lot meets screening criteria. Baseline acceptance testing is followed by lot sample tests, designed to test the cell safety mechanisms to ensure that, in the event of power system malfunction, flight hardware surrounding the PicoSat will not be affected. Cell safety specification testing is performed on this lot of Moli-Energy cells to validate previous screening efforts and ensure lot compliance with NASA standards.

1.2 Applicable Documents

JSC 23642 Rev D, JSC Fastener Integrity Testing Program

ICD-2-19001, Rev. L, Shuttle Orbiter/Cargo Standard Interfaces (CORE)

MIL-HDBK-5H, Metallic Materials and Elements for Aerospace Vehicle Structures, 12/91

MSFC-HDBK-527F/JSC 09604F, Materials Selection List for Space Hardware Systems.

MSFC-SPEC-522B, Design Criteria for Controlling Stress Corrosion Cracking.

NASA-STD-5003, Fracture Control Requirements for Payloads using the Space Shuttle.

NSTS/ISS 13830, Rev. C, Payload Safety Review and Data Submittal Requirements, May 98

NSTS 1700.7B, Safety Policy and Requirements for Payloads using the STS, 1/89

NSTS 14046, Rev E, Payload Verification Requirements, 3/00

NSTS-21000-IDD-SML, Rev. C, Shuttle Orbiter/Small Payload Accommodation Interfaces, 2/98

NASA-STD-5002, Load Analyses of Spacecraft and Payload

NASA-STD-7001, Payload Vibroacoustic Test Criteria

NASA-STD-7002, Payload Test Requirements

2. Cells Procurement

The Aerospace Corporation provided for the procurement of all cells required for flight and lot sample testing. One hundred cells were procured, of which at least 80 were screened for flight, and at least six cells were set aside solely for the purpose of carrying out the flight lot sample/safety mechanism testing. Only fully screened cells will be used for flight.

3. Physical and Electrochemical Characteristics

Characterization testing was performed on all (100%) of the lithium-ion cells constituting the lot, including the flight cells. The testing on the lot sample was completed before any testing on the flight cells was performed.

3.1 Physical Characteristics

All cells were numbered and labeled. Dimensions and weight of all cells were recorded. Statistical information (average values and standard deviation) on the physical characteristics are shown in Table 1. A visual inspection of the cells was made, and no deformations, cracks, or electrolyte leaks were observed.

Table 1. Moli-Energy Li-Ion Cell Weights

SN	Weight (g)	SN	Weight (g)	SN	Weight (g)	SN	Weight (g)
C001	46.014	C032	46.085	C063	46.034	C094	46.033
C002	46.147	C033	46.136	C064	46.032	C095	46.048
C003	46.058	C034	46.036	C065	46.094	C096	46.031
C004	45.985	C035	46.148	C066	45.936	C097	46.030
C005	46.027	C036	46.083	C067	46.083	C098	45.955
C006	45.985	C037	45.962	C068	46.049	C099	46.199
C007	46.097	C038	46.148	C069	45.980	C100	45.903
C008	46.052	C039	46.108	C070	45.984		
C009	46.082	C040	46.106	C071	46.097	Avg Weight: 46.028 g	
C010	45.998	C041	46.040	C072	45.864	Std Dev: 0.075 g	
C011	46.054	C042	46.051	C073	45.882		
C012	45.975	C043	45.973	C074	45.940		
C013	46.045	C044	45.994	C075	46.079		
C014	46.025	C045	45.860	C076	46.038		
C015	45.976	C046	45.877	C077	45.984		
C016	45.992	C047	46.167	C078	45.961		
C017	46.031	C048	46.048	C079	45.902		
C018	46.027	C049	46.072	C080	46.108		
C019	46.076	C050	46.102	C081	45.987		
C020	46.015	C051	46.038	C082	46.024		
C021	45.860	C052	46.056	C083	45.963		
C022	45.992	C053	45.905	C084	45.879		
C023	46.006	C054	46.200	C085	46.125		
C024	45.984	C055	46.121	C086	46.112		
C025	46.012	C056	46.084	C087	46.058		
C026	46.045	C057	46.057	C088	46.057		
C027	45.983	C058	46.021	C089	46.089		
C028	46.003	C059	45.964	C090	46.053		
C029	46.044	C060	45.962	C091	46.081		
C030	45.843	C061	46.084	C092	46.080		
C031	46.008	C062	46.139	C093	45.979		

3.2 Electrochemical Characteristics

The open-circuit voltage (OCV) and closed-circuit voltage (CCV) of the cells was measured and recorded. The OCV of each cell was found to be between 3.6 V and 4.2 V, as specified in the lot acceptance criteria. No further testing was required.

CCV tests were performed with a 2 A current for 30 s. No cell values of CCV below 2.5 V were found.

All cells passed the initial OCV and CCV characterization tests. Results are shown in Table 2.

Table 2. Moli-Energy Li-Ion Cell OCV and CCV Values

SN	OCV	CCV	SN	OCV	CCV	SN	OCV	CCV	SN	OCV	CCV
C001	3.810	3.573	C032	3.809	3.574	C063	3.807	3.581	C094	3.807	3.603
C002	3.810	3.573	C033	3.809	3.574	C064	3.806	3.585	C095	3.807	3.582
C003	3.811	3.567	C034	3.809	3.578	C065	3.809	3.584	C096	3.806	3.582
C004	3.810	3.571	C035	3.810	3.577	C066	3.806	3.583	C097	3.806	3.581
C005	3.811	3.566	C036	3.807	3.585	C067	3.807	3.584	C098	3.806	3.585
C006	3.811	3.576	C037	3.808	3.585	C068	3.806	3.582	C099	3.806	3.579
C007	3.810	3.573	C038	3.808	3.586	C069	3.806	3.586	C100	3.806	3.582
C008	3.809	3.573	C039	3.808	3.584	C070	3.806	3.582			
C009	3.810	3.571	C040	3.807	3.581	C071	3.806	3.583	Average	3.808	3.581
C010	3.810	3.575	C041	3.806	3.587	C072	3.806	3.586	Minimum	3.805	3.566
C011	3.811	3.574	C042	3.807	3.585	C073	3.807	3.584			
C012	3.810	3.576	C043	3.807	3.585	C074	3.805	3.585			
C013	3.811	3.574	C044	3.808	3.582	C075	3.806	3.585			
C014	3.810	3.576	C045	3.808	3.586	C076	3.806	3.585			
C015	3.809	3.574	C046	3.808	3.584	C077	3.806	3.585			
C016	3.806	3.577	C047	3.809	3.583	C078	3.806	3.585			
C017	3.811	3.576	C048	3.809	3.587	C079	3.806	3.585			
C018	3.811	3.575	C049	3.808	3.586	C080	3.806	3.583			
C019	3.811	3.575	C050	3.806	3.581	C081	3.806	3.586			
C020	3.810	3.576	C051	3.806	3.582	C082	3.807	3.583			
C021	3.810	3.578	C052	3.806	3.583	C083	3.806	3.583			
C022	3.810	3.576	C053	3.806	3.585	C084	3.806	3.583			
C023	3.810	3.574	C054	3.808	3.580	C085	3.806	3.584			
C024	3.809	3.576	C055	3.807	3.584	C086	3.806	3.584			
C025	3.809	3.573	C056	3.806	3.584	C087	3.807	3.584			
C026	3.810	3.572	C057	3.807	3.581	C088	3.806	3.585			
C027	3.809	3.571	C058	3.807	3.581	C089	3.807	3.583			
C028	3.808	3.574	C059	3.808	3.584	C090	3.805	3.584			
C029	3.806	3.577	C060	3.808	3.585	C091	3.807	3.584			
C030	3.810	3.575	C061	3.808	3.584	C092	3.806	3.582			
C031	3.809	3.575	C062	3.806	3.586	C093	3.806	3.583			

3.3 Charge/Discharge Cycle

All cells underwent two charge/discharge cycles before being subjected to the lot sample or screening tests below. A derating of 10% was used such that the cells were rated at 2.0 Ah. Charging was performed on each cell using a 1 C (2 A) current to 4.2 V, and held at constant voltage until the current fell to 20 mA. Discharge was at 0.5 C (1 A) to a cutoff voltage of 2.5 V. The capacities of the cells

were recorded. All cells were above the derated capacity of 2.0 Ah. Impedance at 3.7 V was determined using a pulse discharge of 2 A for 30 s.

All cells passed the charge/discharge cycling. Results are shown in Table 3.

Table 3. Moli-Energy Li-Ion Cell Charge/Discharge Cycling Characterization

SN	Capacity (Ah)	Impedance (Ohm)	SN	Capacity (Ah)	Impedance (Ohm)	SN	Capacity (Ah)	Impedance (Ohm)	SN	Capacity (Ah)	Impedance (Ohm)
C001	2.129	0.036	C032	2.145	0.042	C063	2.162	0.030	C094	2.127	0.029
C002	2.154	0.034	C033	2.158	0.032	C064	2.148	0.028	C095	2.154	0.029
C003	2.132	0.032	C034	2.126	0.031	C065	2.161	0.029	C096	2.149	0.029
C004	2.113	0.032	C035	2.148	0.031	C066	2.135	0.028	C097	2.151	0.029
C005	2.135	0.026	C036	2.166	0.028	C067	2.156	0.036	C098	2.140	0.029
C006	2.133	0.033	C037	2.142	0.028	C068	2.147	0.028	C099	2.158	0.030
C007	2.151	0.032	C038	2.163	0.028	C069	2.126	0.027	C100	2.101	0.030
C008	2.125	0.028	C039	2.149	0.028	C070	2.133	0.028			
C009	2.147	0.028	C040	2.161	0.028	C071	2.168	0.029	Average	2.143	0.030
C010	2.137	0.031	C041	2.134	0.028	C072	2.134	0.029			
C011	2.147	0.032	C042	2.156	0.028	C073	2.109	0.029			
C012	2.130	0.031	C043	2.130	0.028	C074	2.125	0.028			
C013	2.146	0.033	C044	2.139	0.027	C075	2.158	0.035			
C014	2.134	0.023	C045	2.114	0.029	C076	2.148	0.027			
C015	2.126	0.028	C046	2.123	0.028	C077	2.145	0.028			
C016	2.121	0.032	C047	2.186	0.029	C078	2.151	0.030			
C017	2.143	0.031	C048	2.149	0.035	C079	2.153	0.028			
C018	2.139	0.032	C049	2.154	0.029	C080	2.159	0.029			
C019	2.142	0.027	C050	2.165	0.031	C081	2.138	0.028			
C020	2.118	0.026	C051	2.151	0.030	C082	2.161	0.029			
C021	2.102	0.031	C052	2.153	0.030	C083	2.138	0.028			
C022	2.142	0.026	C053	2.132	0.029	C084	2.137	0.029			
C023	2.138	0.032	C054	2.182	0.028	C085	2.169	0.028			
C024	2.117	0.032	C055	2.157	0.032	C086	2.153	0.042			
C025	2.136	0.032	C056	2.151	0.028	C087	2.141	0.029			
C026	2.145	0.032	C057	2.161	0.028	C088	2.158	0.028			
C027	2.138	0.032	C058	2.161	0.031	C089	2.171	0.028			
C028	2.108	0.032	C059	2.143	0.030	C090	2.141	0.029			
C029	2.151	0.032	C060	2.120	0.029	C091	2.158	0.028			
C030	2.116	0.032	C061	2.162	0.028	C092	2.154	0.044			
C031	2.128	0.031	C062	2.164	0.029	C093	2.144	0.029			

3.4 Vacuum Leak Test

Fully charged cells were weighed to the nearest hundredth of a gram and placed in a vacuum chamber that is capable of holding less than 0.1 psia pressure. The pressure of the chamber was taken down to less than 0.1 psia at the rate of 8 psi/min. The cells were held under this condition for at least 6 h. The chamber was then pressurized to 14 psia at the rate of 9 psi/min. The cells were removed from the chamber and checked for any visual changes, such as cracks, leaks, or venting. They were then placed outside the chamber at ambient temperature for at least 2 h and then weighed again. The difference in the weight of the cells was less than 1%. Results are shown in Table 4.

Table 4. Moli-Energy Li-Ion Cell Weights After Vacuum Leak Test

SN	Initial Weight (g)	Final Weight (g)	Difference (g)	% Change	SN	Initial Weight (g)	Final Weight (g)	Difference (g)	% Change	
C001	46.01	46.01	0.00	-0.002%	C051	46.04	46.04	0.00	0.000%	
C002	46.15	46.15	0.00	0.000%	C052	46.06	46.06	0.00	0.000%	
C003	46.06	46.06	0.00	0.000%	C053	45.91	45.91	0.00	0.000%	
C004	45.99	45.98	0.00	-0.002%	C054	46.20	46.20	0.00	-0.004%	
C005	46.03	46.03	0.00	0.000%	C055	46.12	46.12	0.00	0.000%	
C006	45.99	45.99	0.00	0.000%	C056	46.08	46.08	0.00	0.000%	
C007	46.10	46.10	0.00	0.000%	C057	46.06	46.06	0.00	-0.002%	
C008	46.05	46.05	0.00	0.000%	C058	46.02	46.02	0.00	-0.002%	
C009	46.08	46.08	0.00	-0.002%	C059	45.96	45.96	0.00	0.000%	
C010	46.00	46.00	0.00	0.000%	C060	45.96	45.96	0.00	-0.002%	
C011	46.05	46.05	0.00	0.000%	C061	46.08	46.08	0.00	0.000%	
C012	45.98	45.86	0.12	-0.252%	C062	46.14	46.14	0.00	0.000%	
C013	46.05	46.05	0.00	0.000%	C063	46.03	46.03	0.00	-0.002%	
C014	46.03	46.03	0.00	0.000%	C064	46.03	46.03	0.00	-0.005%	
C015	45.98	45.98	0.00	0.000%	C065	46.09	46.09	0.00	-0.003%	
C016	45.99	45.99	0.00	0.000%	C066	45.94	45.93	0.00	-0.004%	
C017	46.03	46.03	0.00	-0.002%	C067	46.08	46.08	0.00	-0.002%	
C018	46.03	46.03	0.00	-0.002%	C068	46.05	46.05	0.00	-0.002%	
C019	46.08	46.08	0.00	-0.002%	C069	45.98	45.98	0.00	-0.005%	
C020	46.02	46.01	0.00	-0.002%	C070	45.98	45.98	0.00	-0.002%	
C021	45.86	45.97	0.11	0.249%	C071	46.10	46.10	0.00	-0.002%	
C022	45.99	45.99	0.00	0.000%	C072	45.86	45.86	0.00	-0.004%	
C023	46.01	46.01	0.00	0.000%	C073	45.88	45.88	0.00	-0.004%	
C024	45.98	45.98	0.00	-0.004%	C074	45.94	45.94	0.00	-0.004%	
C025	46.01	46.01	0.00	-0.002%	C075	46.08	46.08	0.00	-0.003%	
C026	46.05	46.05	0.00	0.000%	C076	46.04	46.04	0.00	-0.004%	
C027	45.98	45.98	0.00	-0.004%	C077	45.98	45.98	0.00	-0.003%	
C028	46.00	46.00	0.00	-0.002%	C078	45.96	45.96	0.00	-0.004%	
C029	46.04	46.04	0.00	-0.002%	C079	45.90	45.90	0.00	-0.003%	
C030	45.84	45.84	0.00	0.000%	C080	46.11	46.11	0.00	-0.002%	
C031	46.01	46.01	0.00	0.000%	C081	45.99	45.99	0.00	-0.002%	
C032	46.09	46.09	0.00	0.002%	C082	46.02	46.02	0.00	-0.003%	
C033	46.14	46.14	0.00	0.000%	C083	45.96	45.96	0.00	-0.002%	
C034	46.04	46.04	0.00	0.004%	C084	45.88	45.88	0.00	-0.004%	
C035	46.15	46.15	0.00	0.002%	C085	46.13	46.12	0.00	-0.001%	
C036	46.08	45.97	0.11	-0.237%	C086	46.11	46.11	0.00	-0.001%	
C037	45.96	46.16	0.20	0.431%	C087	46.06	46.06	0.00	-0.002%	
C038	46.15	46.17	0.03	0.056%	C088	46.06	46.06	0.00	-0.002%	
C039	46.11	46.03	0.08	-0.169%	C089	46.09	46.09	0.00	-0.002%	
C040	46.11	46.12	0.01	0.026%	C090	46.05	46.05	0.00	-0.002%	
C041	46.04	46.06	0.02	0.041%	C091	46.08	46.08	0.00	-0.004%	
C042	46.05	46.06	0.01	0.026%	C092	46.08	46.08	0.00	-0.004%	
C043	45.97	46.01	0.03	0.070%	C093	45.98	45.98	0.00	-0.004%	
C044	45.99	46.08	0.09	0.196%	C094	46.03	46.03	0.00	-0.005%	
C045	45.86	45.87	0.01	0.028%	C095	46.05	46.05	0.00	-0.004%	
C046	45.88	45.89	0.01	0.024%	C096	46.03	46.03	0.00	-0.003%	
C047	46.17	45.98	0.18	-0.396%	C097	46.03	46.03	0.00	-0.004%	
C048	46.05	45.97	0.07	-0.161%	C098	45.96	45.95	0.00	-0.002%	
C049	46.07	46.06	0.01	-0.028%	C099	46.20	46.20	0.00	-0.003%	
C050	46.10	46.10	0.00	-0.004%	C100	45.90	45.90	0.00	-0.003%	
						Initial (g)	Final (g)			
						Average	46.03	46.03		

One discharge/charge/discharge cycle was carried out on the cells after the vacuum leak test. Capacity values before and after the test are shown in Table 5. All tested cells were within 95% of their initial capacity.

Note: Cells C009 and C023 were misplaced following being weighed after the vacuum leak test and prior to running the capacity check. If they are found, they will not be included as part of the flight cells.

Table 5. Moli-Energy Li-Ion Cell Capacity Check After Vacuum Leak Test

SN	Capacity BEFORE	Capacity AFTER	% of before	SN	Capacity BEFORE	Capacity AFTER	% of before
C001	2.129	2.148	100.9%	C053	2.132	2.138	100.3%
C002	2.154	2.174	100.9%	C054	2.182	2.174	99.6%
C003	2.132	2.149	100.8%	C055	2.157	2.155	99.9%
C004	2.113	2.143	101.4%	C056	2.151	2.149	99.9%
C005	2.135	2.159	101.1%	C057	2.161	2.158	99.8%
C006	2.133	2.161	101.3%	C058	2.161	2.162	100.0%
C007	2.151	2.170	100.9%	C059	2.143	2.157	100.7%
C008	2.125	2.147	101.1%	C060	2.120	2.134	100.7%
C010	2.137	2.150	100.6%	C061	2.162	2.160	99.9%
C011	2.147	2.101	97.9%	C062	2.164	2.163	100.0%
C012	2.130	2.087	98.0%	C063	2.162	2.165	100.2%
C013	2.146	2.156	100.5%	C064	2.148	2.148	100.0%
C014	2.134	2.092	98.0%	C065	2.161	2.166	100.2%
C015	2.126	2.143	100.8%	C066	2.135	2.145	100.5%
C016	2.121	2.145	101.1%	C067	2.156	2.152	99.8%
C017	2.143	2.157	100.6%	C068	2.147	2.146	100.0%
C018	2.139	2.154	100.7%	C069	2.126	2.129	100.1%
C019	2.142	2.155	100.6%	C070	2.133	2.137	100.2%
C020	2.118	2.154	101.7%	C071	2.168	2.165	99.9%
C021	2.102	2.066	98.3%	C072	2.134	2.149	100.7%
C022	2.142	2.101	98.1%	C073	2.109	2.135	101.2%
C024	2.117	2.140	101.1%	C074	2.125	2.137	100.5%
C025	2.136	2.094	98.0%	C075	2.158	2.154	99.8%
C026	2.145	2.097	97.8%	C076	2.148	2.157	100.4%
C027	2.138	2.159	101.0%	C077	2.145	2.154	100.4%
C028	2.108	2.137	101.4%	C078	2.151	2.146	99.8%
C029	2.151	2.169	100.8%	C079	2.153	2.164	100.5%
C030	2.116	2.147	101.5%	C080	2.159	2.159	100.0%
C031	2.128	2.086	98.0%	C081	2.138	2.138	100.0%
C032	2.145	2.154	100.4%	C082	2.161	2.158	99.8%
C033	2.158	2.168	100.5%	C083	2.138	2.142	100.2%
C034	2.126	2.145	100.9%	C084	2.137	2.149	100.6%
C035	2.148	2.157	100.4%	C085	2.169	2.169	100.0%
C036	2.166	2.161	99.7%	C086	2.153	2.150	99.9%
C037	2.142	2.147	100.2%	C087	2.141	2.151	100.5%
C038	2.163	2.155	99.6%	C088	2.158	2.158	100.0%
C039	2.149	2.145	99.8%	C089	2.171	2.165	99.7%
C040	2.161	2.152	99.6%	C090	2.141	2.141	100.0%
C041	2.134	2.147	100.6%	C091	2.158	2.156	99.9%
C042	2.156	2.149	99.7%	C092	2.154	2.157	100.2%
C043	2.130	2.143	100.6%	C093	2.144	2.145	100.0%

SN	Capacity BEFORE	Capacity AFTER	% of before	SN	Capacity BEFORE	Capacity AFTER	% of before
C044	2.139	2.144	100.2%	C094	2.127	2.137	100.5%
C045	2.114	2.129	100.7%	C095	2.154	2.151	99.9%
C046	2.123	2.141	100.9%	C096	2.149	2.148	99.9%
C047	2.186	2.187	100.1%	C097	2.151	2.160	100.4%
C048	2.149	2.143	99.7%	C098	2.140	2.151	100.5%
C049	2.154	2.148	99.7%	C099	2.158	2.157	100.0%
C050	2.165	2.164	100.0%	C100	2.101	2.124	101.1%
C051	2.151	2.158	100.3%				
C052	2.153	2.158	100.2%				
					Before	After	
				Average	2.143	2.147	

4. Lot Sample Tests

The objective of these tests is to verify that the safety features and characteristics of the new lot of flight Li-Ion cells are similar to the ones tested and certified for use on the Space Shuttle and International Space Station; the cells are cylindrical Li-Ion cells with a nominal voltage of 3.75 V and a capacity of 2200 mAh.

The tests have been designed to simulate possible power system anomalies leading to shorting, overcharging or overdischarging of flight cells that could occur prior to ejection of the PicoSat from the Shuttle or ISS. The requirement that the lot sample cells pass the following tests ensures that in the event of an on-orbit anomaly, flight hardware surrounding a flight cell(s) will not be damaged.

Lot sample testing was carried out on eight of the cells constituting the lot; the eight cells that were chosen had physical and electrochemical characteristics resembling the flight lot and are representative of potential flight cells. The vibrated cells underwent the lot sample tests described below. Current, voltage, and temperature versus time and the capacities (wherever applicable) was documented. Tests were carried out in the order shown to minimize the number of cells used for lot sample testing.

The results and observations confirmed the existing database on the abuse tolerance characteristics of the cells. Necessary precautions were taken during all phases of testing.

If any single cell had failed the criteria imposed for the lot sample testing, the whole lot would have been rejected.

4.1 Vibration Test

Eight fully charged cells were vibrated using the following spectrum for 15 min in each of the x, y, and z axes.

Frequency (Hz)	Level
20-80	+3 dB/octave
80-350	0.1 g ² /Hz
350-2000	-3 dB/octave

Each cell's OCV was measured following vibration, and then was subjected to a discharge/charge/discharge to confirm functionality. The pass criteria are: the difference in OCV of the cells before and after vibration was within $\pm 0.5\%$; the capacity obtained on the second discharge was greater than 95% of the capacity obtained in the second discharge test of Subsection 3.3 of the test plan for that particular cell.

The cells passed the OCV and capacity criteria. Results are shown in Table 6.

Table 6. Moli-Energy Li-Ion Cell Performance Before and After Vibration Test

SN	OCV (V)		% change	Capacity		% of before
	BEFORE	AFTER		BEFORE	AFTER	
C022	4.161	4.160	-0.02%	2.142	2.085	97.33%
C011	4.161	4.160	-0.02%	2.147	2.086	97.17%
C012	4.160	4.159	-0.02%	2.130	2.082	97.73%
C014	4.161	4.160	-0.02%	2.134	2.077	97.34%
C021	4.161	4.160	-0.02%	2.102	2.055	97.80%
C025	4.161	4.160	-0.02%	2.136	2.081	97.43%
C026	4.162	4.161	-0.02%	2.145	2.087	97.29%
C031	4.161	4.160	-0.02%	2.128	2.074	97.43%

4.2 Cell Safety Mechanism Testing

Two cells were used for each of the safety mechanism tests.

4.2.1 Short Circuit

Cells were charged individually with a 1 C (2 A) current to 4.2 V and held at constant voltage until the current fell to 20 mA. Each cell was subjected to a short circuit of less than 0.05 ohms. External temperature, current, and voltage of the cells were recorded during the tests. A positive temperature coefficient (PTC) device acts as a resettable fuse, and is expected to be activated within a few seconds on the application of a short circuit.

When the PTC was activated, the source of the short circuit was removed. If the PTC was not activated within a few seconds, cell temperature decrease was verified before removing the source of the short circuit. After a wait period of at least one hour, two charge/discharge cycles were performed. Charge/discharge curves displaying current and voltage as a function of time were plotted. There was no significant temperature change during cycling.

Cells C014 and C022 underwent short-circuit testing. Results are shown in Figure 1. Upon examination of each cell's respective current curve, it is apparent that both cells displayed activation of the PTC device within seconds of the short circuit. Note the abrupt change in the cells' current slope. The drop in current below about 60 A is due to an increase in impedance within the cell, caused by the activation of the cell's PTC device. Cells C014 and C022 passed the short-circuit testing. Shown in Figure 2 is a post-short-circuit discharge capacity curve comparison to baseline discharge capacity taken after the qualification-level vibration testing. The capacity curves of both cells overlap very closely in the comparison figure; they may be difficult to discern at multiple points. A zoomed plot of the end-of-discharge capacities is inset in the same figure.

4.2.2 Cell Overdischarge

The cells allotted for this test were charged with a 1 C (2 A) current to 4.2 V, and held at constant voltage until the current fell to 20 mA. Cells were then discharged at a 1 C (2 A) rate to 0.0 V; the discharge was continued to 150% of original capacity (3.0 Ah) using the same current. Two standard charge/discharge cycles were then attempted.

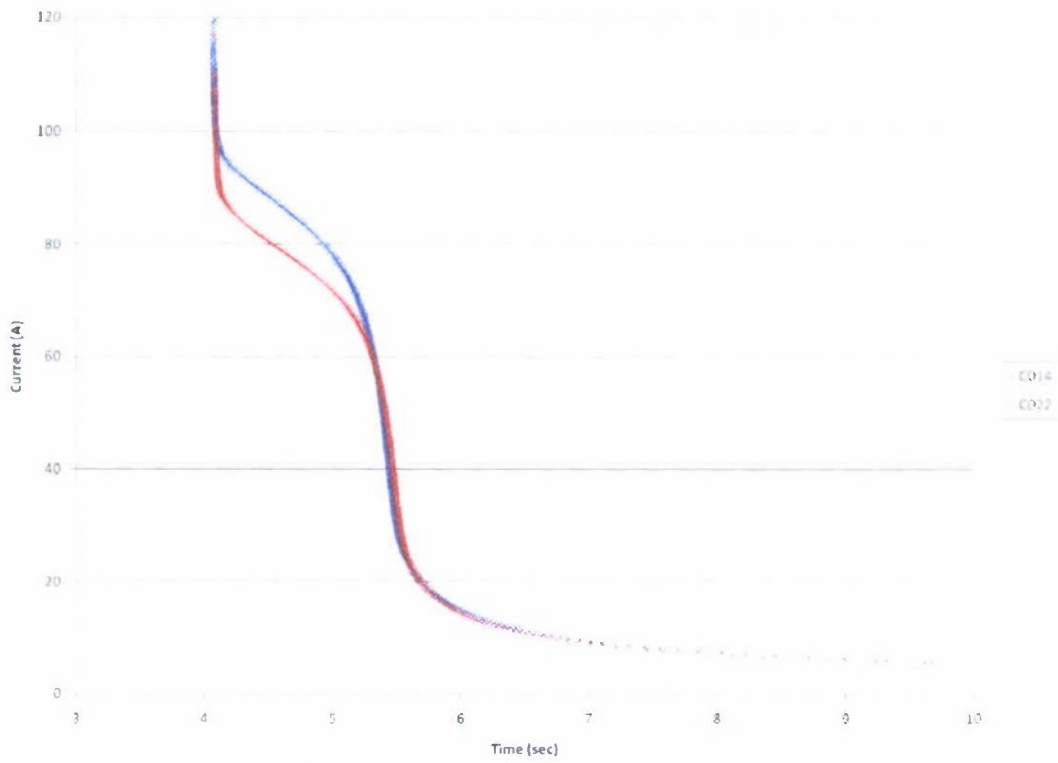


Figure 1. Cell current characteristics during short circuit.

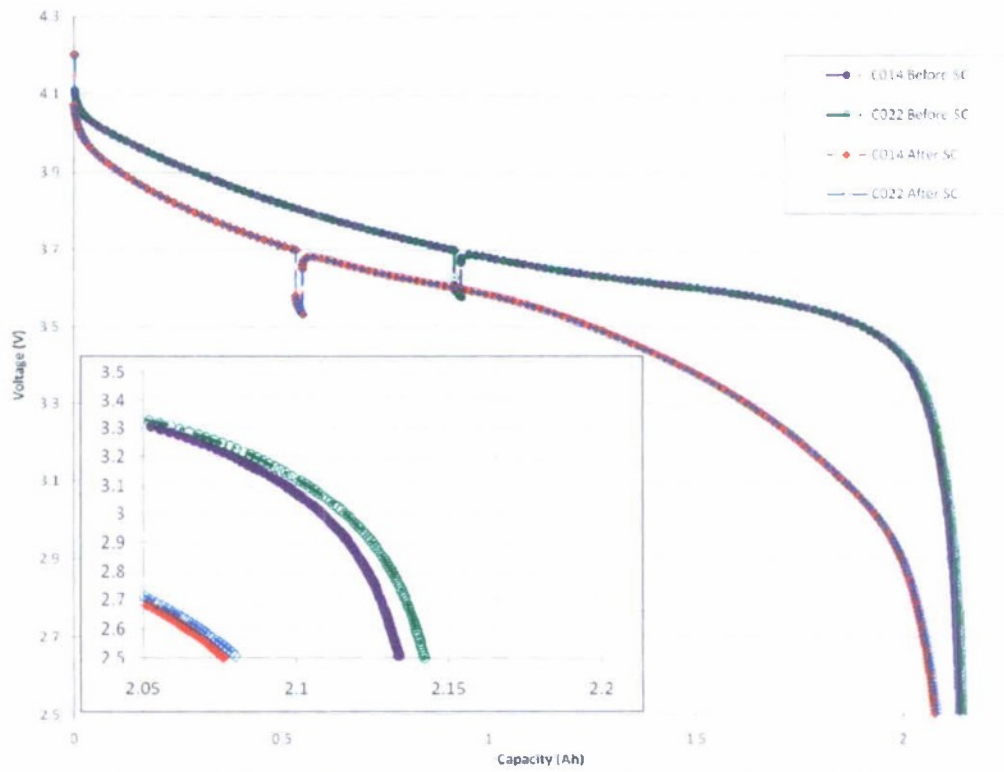


Figure 2. Cell discharge capacity comparison before and after short circuit.

Cells C012 and C026 underwent the overdischarge test. Although the cells displayed increases in temperature during the overdischarge, cell rupture, fire, or explosion did not occur. The cells did not perform during the follow-up charge/discharge cycles; this condition was not a failure criteria. The cells passed the overdischarge test.

Cell discharge voltages are shown in Figure 3. Note the region where the cells discharged below 0.0 V.

4.2.3 Cell Overcharge

The cells were charged at a 1 C (2 A) rate to 4.2 V until the current fell below 50 mA, and then overcharged at a 1 C (2 A) rate until the current interrupt device (CID) was activated. The overcharge voltage target was set for 10 V to allow sufficient headroom for the CID to activate. The CID is expected to activate near 5.0 V after a period of internal cell pressure buildup due to overcharge conditions.

Cells C011 and C021 underwent the overcharge test. Cell temperatures were monitored. Cell C011 displayed a temperature change from 22°C to 65°C. Cell C021 displayed a temperature change from 21°C to 55°C. Both cells displayed activation of their CID, the point at which the cells went open circuit. Monitored cell voltage maximums were near 5.0 V at the time when their CID activated. The cell characteristics of C021 are shown in Figure 4; CID activation is apparent at the point at which the voltage curve goes abruptly off scale, and the current curve drops to zero.

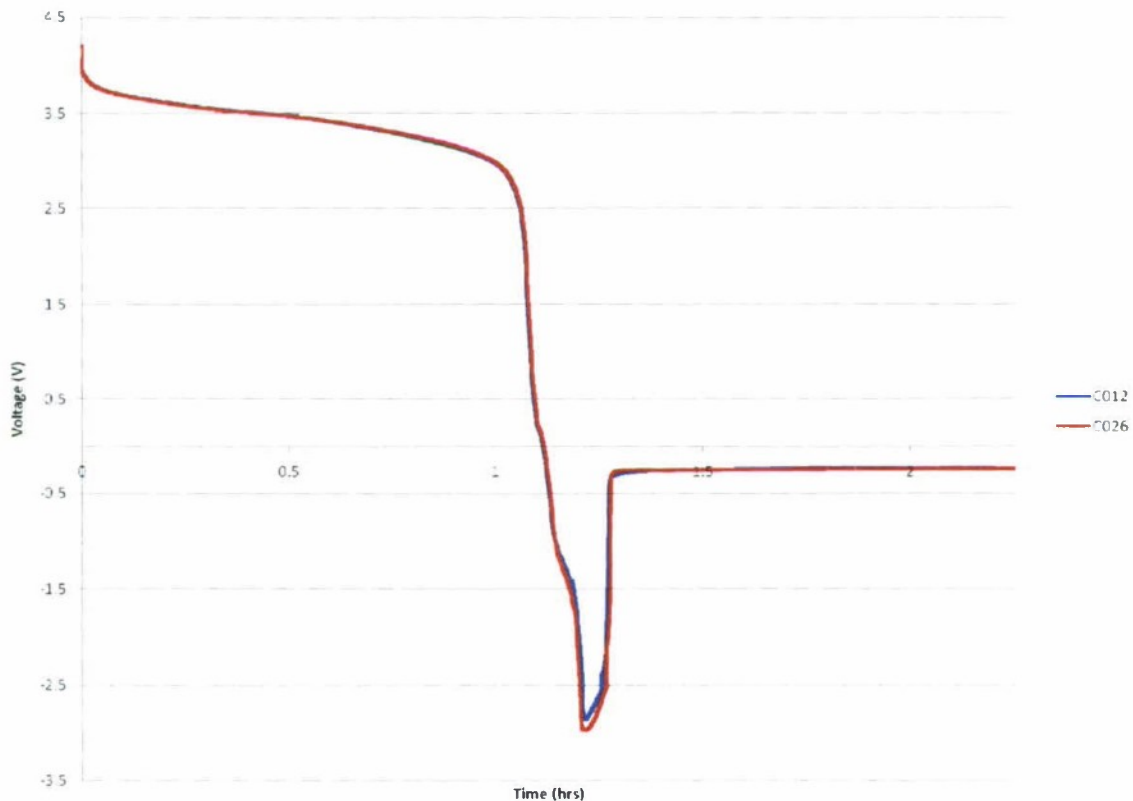


Figure 3. Cell overdischarge voltage characteristics.

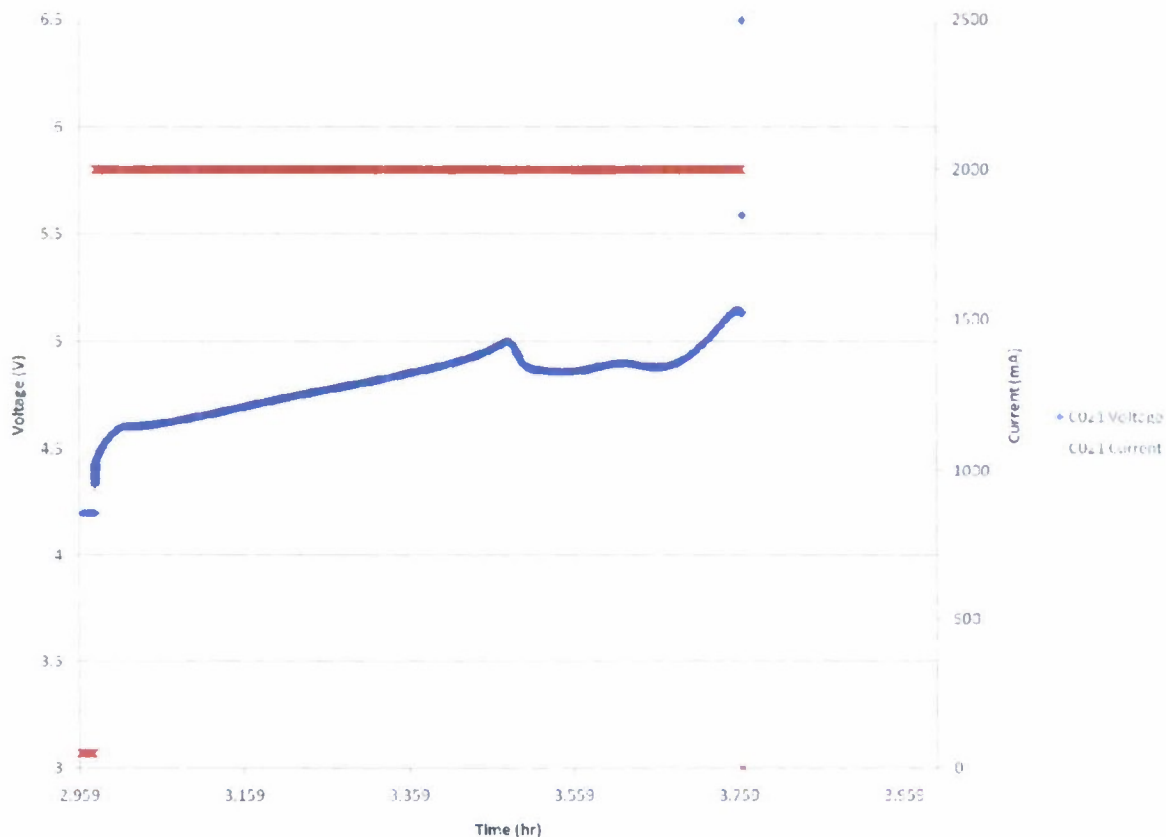


Figure 4. Cell C021 overcharge voltage characteristics.

It should be noted that the test was run incorrectly on cell C011. C011 was allowed to charge to 4.2 V until the current fell below 20 mA before being subjected to overcharge conditions. The overcharge test was also paused briefly before it resumed. The external cell temperature reached near 65°C, about 10°C higher than cell C021. Despite the incorrect test procedure, the cell's CID still activated.

Due to incorrect testing of cell C011, two additional cells were tested to ensure reproducibility of the results. Cells C025 and C031 also underwent the overcharge test. Cell C025 displayed a temperature change from 24°C to 48°C. Cell C031 displayed a temperature change from 22°C to 72°C. Both cells displayed activation of their CID, apparent by examining the point at which the voltage curve goes abruptly off scale, and the current curve drops to zero, visible in Figures 5 and 6.

No cell rupture, fire, or explosion occurred in any of the cells, including the incorrectly tested cell. The cells passed the overcharge test.

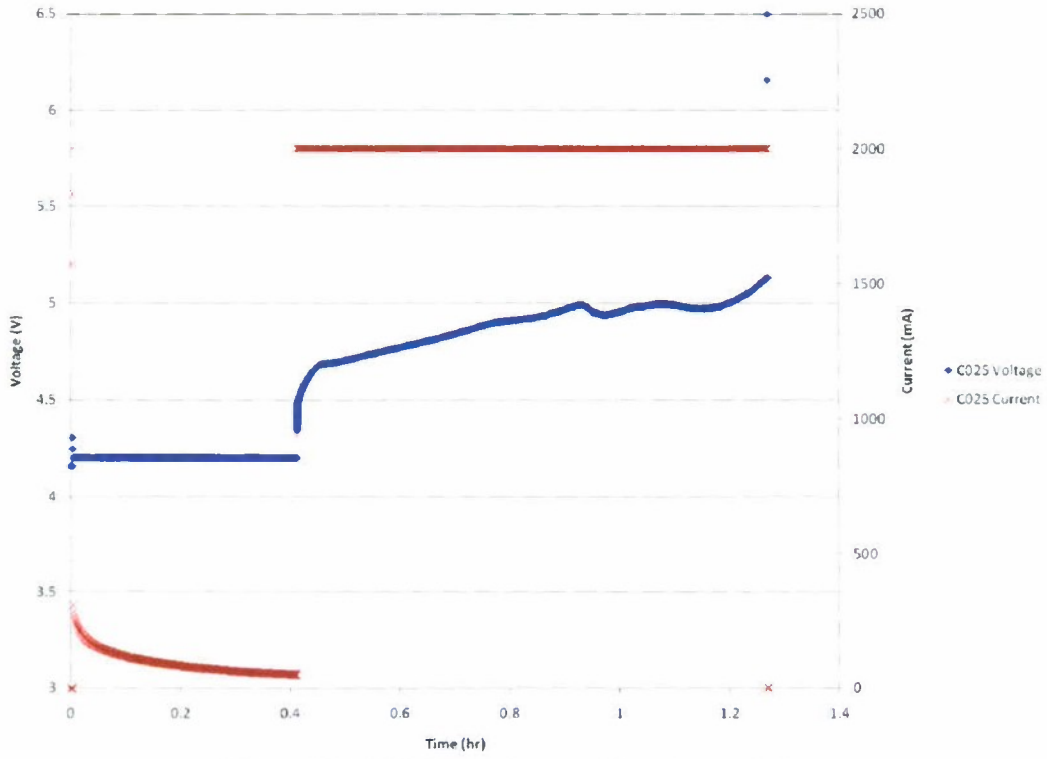


Figure 5. Cell C025 overcharge voltage characteristics.

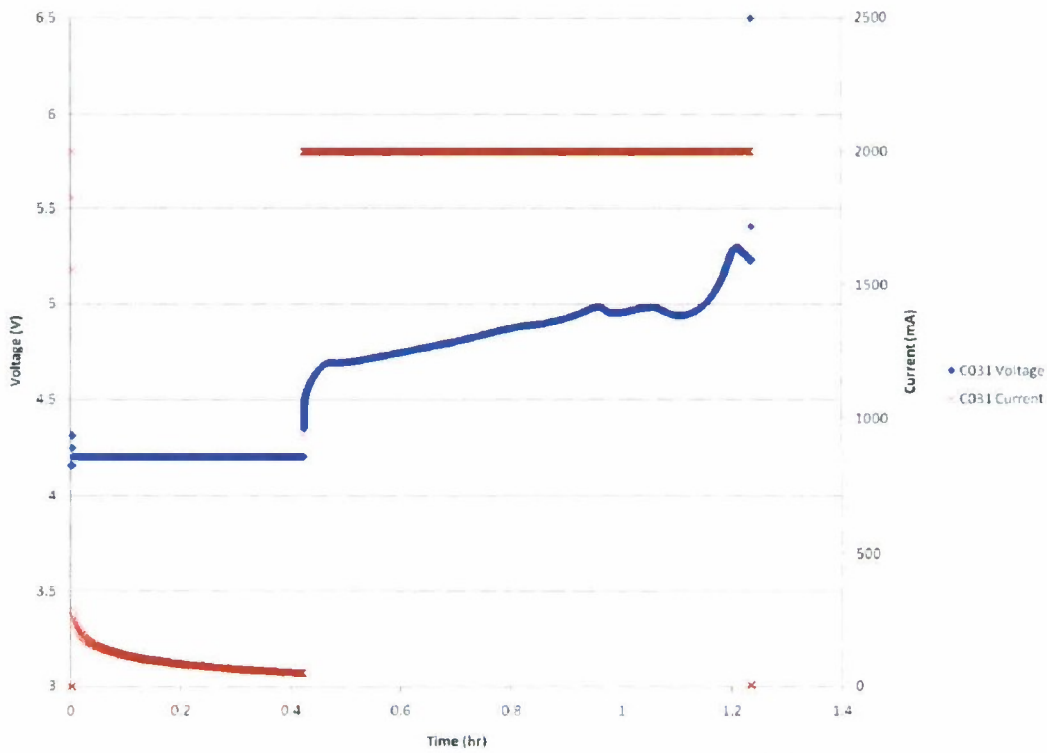


Figure 6. Cell C031 overcharge voltage characteristics.

5. Screening of Flight Cells

Screening of flight cells was completed following lot sample testing. Screening consisted of charging the cells to 4.2 V and holding at constant voltage until current fell below 20 mA, and was followed by a separate vibration test and charge/discharge cycles.

Vibration testing was performed using the spectrum below for one minute in each of the x, y, and z axes.

Frequency	Level
20–80	+3 dB/octave
80–350	0.067 g ² /Hz
350–2000	-3 dB/octave

OCV measurements were taken before and after vibration. Charge/discharge cycles were also performed. OCVs before and after vibration were within $\pm 0.5\%$, and capacity was greater than 95% of the capacity obtained during initial characterization. The cells passed the flight screening tests. Results are shown in Table 7.

Table 7. Moli-Energy Li-Ion Cell Flight Screening Vibration Test Performance Summary

SN	OCV (V) BEFORE	OCV (V) AFTER	% change	Capacity BEFORE	Capacity AFTER	% of before
C001	4.181	4.171	-0.24%	2.129	2.107	98.95%
C002	4.181	4.171	-0.23%	2.154	2.139	99.29%
C003	4.181	4.172	-0.23%	2.132	2.104	98.68%
C004	4.181	4.171	-0.23%	2.113	2.098	99.27%
C005	4.181	4.171	-0.23%	2.135	2.119	99.26%
C006	4.182	4.172	-0.24%	2.133	2.115	99.16%
C007	4.181	4.171	-0.24%	2.151	2.129	99.01%
C008	4.181	4.171	-0.24%	2.125	2.107	99.17%
C010	4.181	4.172	-0.22%	2.137	2.112	98.83%
C013	4.182	4.173	-0.21%	2.146	2.121	98.84%
C015	4.181	4.171	-0.23%	2.126	2.104	98.97%
C016	4.181	4.172	-0.22%	2.121	2.1	98.97%
C017	4.181	4.171	-0.23%	2.143	2.118	98.80%
C018	4.182	4.172	-0.23%	2.139	2.114	98.87%
C019	4.179	4.171	-0.20%	2.142	2.119	98.92%
C020	4.18	4.172	-0.18%	2.118	2.097	99.00%
C024	4.179	4.172	-0.17%	2.117	2.089	98.67%
C027	4.179	4.171	-0.18%	2.138	2.116	98.97%
C028	4.179	4.172	-0.17%	2.108	2.092	99.24%
C029	4.178	4.17	-0.19%	2.151	2.134	99.21%
C030	4.179	4.171	-0.19%	2.116	2.103	99.40%
C032	4.179	4.171	-0.20%	2.145	2.122	98.90%
C033	4.179	4.171	-0.19%	2.158	2.136	98.95%
C034	4.179	4.172	-0.18%	2.126	2.103	98.92%
C035	4.181	4.172	-0.22%	2.148	2.119	98.65%

SN	OCV (V) BEFORE	OCV (V) AFTER	% change	Capacity BEFORE	Capacity AFTER	% of before
C036	4.179	4.171	-0.19%	2.166	2.132	98.42%
C037	4.179	4.172	-0.16%	2.142	2.111	98.56%
C038	4.179	4.173	-0.16%	2.163	2.114	97.71%
C039	4.18	4.173	-0.17%	2.149	2.104	97.88%
C040	4.179	4.171	-0.18%	2.161	2.112	97.72%
C041	4.178	4.171	-0.18%	2.134	2.109	98.84%
C042	4.179	4.172	-0.17%	2.156	2.113	98.04%
C043	4.179	4.172	-0.18%	2.13	2.104	98.77%
C044	4.179	4.17	-0.22%	2.139	2.108	98.55%
C045	4.18	4.173	-0.16%	2.114	2.093	99.00%
C046	4.179	4.171	-0.19%	2.123	2.1	98.92%
C047	4.149	4.144	-0.11%	2.186	2.158	98.70%
C048	4.18	4.172	-0.18%	2.149	2.104	97.90%
C049	4.179	4.172	-0.17%	2.154	2.114	98.14%
C050	4.178	4.171	-0.17%	2.165	2.131	98.42%
C051	4.178	4.171	-0.18%	2.151	2.124	98.77%
C052	4.178	4.172	-0.13%	2.153	2.122	98.53%
C053	4.178	4.171	-0.17%	2.132	2.097	98.35%
C054	4.18	4.174	-0.13%	2.182	2.137	97.95%
C055	4.177	4.17	-0.17%	2.157	2.118	98.20%
C056	4.177	4.171	-0.15%	2.151	2.107	97.95%
C057	4.178	4.172	-0.16%	2.161	2.12	98.10%
C058	4.177	4.171	-0.16%	2.161	2.125	98.32%
C059	4.177	4.17	-0.16%	2.143	2.114	98.68%
C060	4.177	4.171	-0.15%	2.12	2.092	98.66%
C061	4.15	4.145	-0.12%	2.162	2.127	98.37%
C062	4.177	4.17	-0.16%	2.164	2.132	98.52%
C063	4.178	4.172	-0.17%	2.162	2.139	98.94%
C064	4.178	4.172	-0.15%	2.148	2.117	98.57%
C065	4.179	4.174	-0.12%	2.161	2.131	98.64%
C066	4.179	4.173	-0.15%	2.135	2.11	98.82%
C067	4.177	4.171	-0.15%	2.156	2.117	98.19%
C068	4.178	4.173	-0.13%	2.147	2.106	98.13%
C069	4.179	4.173	-0.14%	2.126	2.088	98.19%
C070	4.178	4.172	-0.15%	2.133	2.097	98.32%
C071	4.177	4.171	-0.15%	2.168	2.134	98.42%
C072	4.177	4.171	-0.15%	2.134	2.117	99.18%
C073	4.177	4.171	-0.14%	2.109	2.095	99.32%
C074	4.178	4.171	-0.16%	2.125	2.099	98.74%
C075	4.177	4.17	-0.16%	2.158	2.119	98.20%
C076	4.177	4.17	-0.15%	2.148	2.122	98.79%
C077	4.177	4.171	-0.15%	2.145	2.12	98.84%
C078	4.177	4.171	-0.15%	2.151	2.106	97.92%
C079	4.177	4.172	-0.12%	2.153	2.127	98.80%
C080	4.177	4.171	-0.16%	2.159	2.127	98.52%
C081	4.177	4.171	-0.15%	2.138	2.11	98.67%
C082	4.178	4.173	-0.12%	2.161	2.122	98.21%
C083	4.177	4.171	-0.15%	2.138	2.105	98.46%
C084	4.176	4.17	-0.15%	2.137	2.117	99.03%
C085	4.177	4.17	-0.15%	2.169	2.141	98.71%
C086	4.176	4.17	-0.16%	2.153	2.121	98.52%
C087	4.178	4.171	-0.15%	2.141	2.114	98.74%

SN	OCV (V) BEFORE	OCV (V) AFTER	% change	Capacity BEFORE	Capacity AFTER	% of before
C088	4.177	4.171	-0.14%	2.158	2.123	98.36%
C089	4.177	4.172	-0.13%	2.171	2.132	98.21%
C090	4.178	4.172	-0.14%	2.141	2.111	98.60%
C091	4.177	4.172	-0.14%	2.158	2.121	98.32%
C092	4.176	4.17	-0.15%	2.154	2.122	98.55%
C093	4.177	4.171	-0.14%	2.144	2.107	98.28%
C094	4.179	4.173	-0.13%	2.127	2.097	98.59%
C095	4.177	4.171	-0.15%	2.154	2.114	98.14%
C096	4.177	4.17	-0.16%	2.149	2.111	98.23%
C097	4.179	4.172	-0.18%	2.151	2.13	99.04%
C098	4.179	4.173	-0.15%	2.14	2.116	98.85%
C099	4.177	4.17	-0.16%	2.158	2.128	98.59%
C100	4.178	4.171	-0.16%	2.101	2.078	98.91%
Average	4.178	4.171	-0.17%	2.144	2.115	98.63%

6. Summary

This report contains results from the sample testing as well as the flight screening required for flight certification of a new lot of Moli-Energy Li-Ion 2200-mAh, 3.75-V cells to be used for the PSSC Testbed follow-up mission. Lot characterization testing began upon receipt of a new lot of Moli-Energy ICR-18650H cells in March 2009. The lot was screened for flight certification according to NASA standards. Cell-level characterization of all flight cells from the lot and safety mechanism testing on a subset of cells was performed. The safety mechanism testing consisted of external short circuit, overcharge, and overdischarge tests; the cells passed all testing.

Reference

- i. Halpine, J. S.; Liu, S.; and J. Lee, "Li-Ion Cell Specification for Lot Testing and Flight Screening Testing Results," Aerospace Report No. TOR-2009(8511)-10. 20 October 2009.