2005 NASA Aerospace Battery Workshop
Huntsville, Nov. 29 – Dec. 1

Current Status of Cycle-Life Testing for Large-Capacity Lithium-Ion Cells Simulated Spacecraft Operation at JAXA

Hitoshi Naito, Xianming Wang, Chisa Yamada, Go Segami, and Koichi Kibe

Japan Aerospace Exploration Agency (JAXA)

宇宙航空研究開発機構
Japan Aerospace Exploration Agency

Development status in JAPAN

Manufacturer	Cell	Spacecraft	Note
GYT(JSB), GYT/Melco,	10 - 190 Ah	SERVIS-1, Thaicom-4, (SERVIS-2,H-IIA)	Balancing circuit. GEO satellite
MHI	15Ah		Commercial use
IA (HVE)	6.5 - 90 Ah	M-V (SERVIS-2)	Commercial use
Furukawa	13.2Ah	Hayabusa	Science Mission
COTS*	1-3Ah	Reimei, (Piggyback)	Small Satellite Commercial use

*Commercial off-the-shelf

History of large lithium-ion cells at JAXA

Fiscal year	1994	96	98	2000	02	04	06	08	10	12
Flexibility investigation	1.0 Ah-class commercial cells Max. cycle life: LEO 23,000 ↔									
Development				10-100 Ah-class space cells Max. cycle life: LEO 30,000, GEO 1,800 ←						
Application								LEO satellite, HTV, Rocket ←		

HTV: H-IIA transfer vehicle

Development purpose

1) Develop lightweight large lithium-ion cells with high energy density of above 100 Wh/kg at a battery level
2) Produce prototypes of high-capacity lithium-ion cells with different designs and materials
3) Conduct cycle-life testing of high-capacity lithium-ion cells simulated LEO and GEO operations
4) Find the optimum operation conditions (taper voltage, charge current, temperature, storage duration)
5) Improve safety and reliability in a space environment (vacuum, radiation, vibration)

Design principle

Active material	Type	Parameter
Cathode	$LiCoO_2$, $LiMn_2O_4$, $LiNi_{1-x-y}Co_xAl_yO_2$	Thickness
Anode	Graphite, (non-graphite)	Thickness
Electrolyte	Alkyl carbonate mixed solvent	Additives, composition

Cell Design	Mechanical modification	Safety vent, welding Process

Main samples evaluated at JAXA

(Tsukuba Space Center)

Sample type		Testing condition	Status
Graphite/ $LiCoO_2$	10 Ah cell	LEO, DOD: 25%, 40%, 15ºC	10,000
	40 Ah cell	LEO, DOD: 40%, 15ºC	3,000
	100 Ah cell	LEO, DOD: 25%, 40%, 15ºC GEO, DOD: 80%, 15ºC HTV, DOD: 40%, 35ºC	30,000 1,800 3,300 end
	100 Ah battery	GEO, DOD: 40-70%, 15ºC	21 seasons
Graphite/ $LiNi_{1-x-y}Co_xAl_yO_2$	50 Ah cell	GEO, DOD: 80%, 15ºC	4 Season
Non-graphite/ $LiMn_2O_4$	9.5 Ah cell	LEO, DOD: 25%, 15ºC	6,000
Graphite/ $LiMn_2O_4$	14.6 Ah cell	LEO, DOD: 25%, 15ºC	6,000

Topics in this presentation

(1) Progress in long-term cycle-life testing of lithium-ion cells (batteries) simulated spacecraft operation

(2) High-rate design with thin electrode layer for LEO applications

(3) Performance comparison of lithium-ion cells with different electrolyte materials

(1) Typical life performance

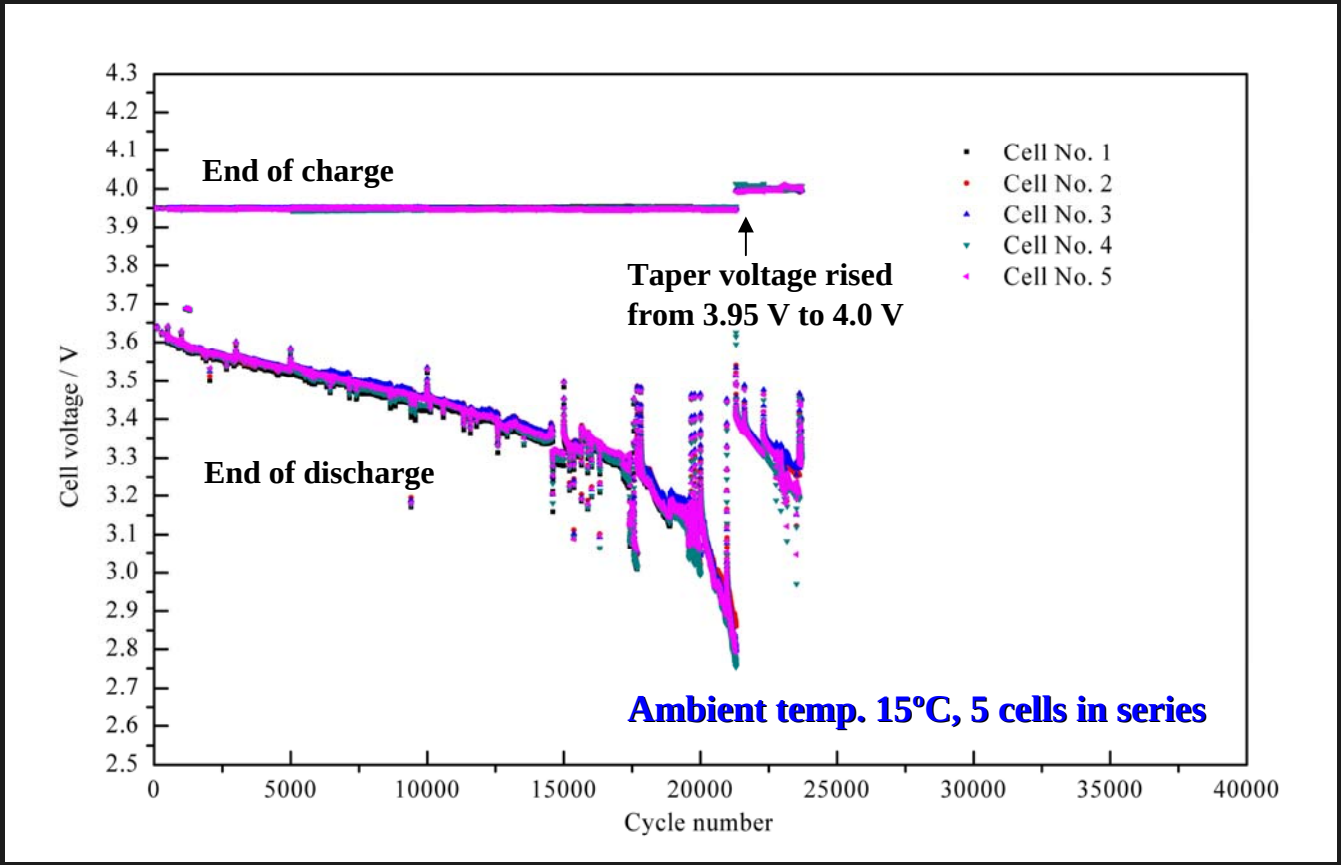
100-Ah cell with graphite anode and $LiCoO_2$ cathode

Manufactured by
GS-Yuasa Technology Ltd.

Cell type		Elliptic cylinder
Cathode		$LiCoO_2$
Anode		Graphite
Capacity	Rated	100
	Nominal	110
Nominal voltage, V		3.7
Weight, g		2,800
Dimensions, mm	Width	50
	Length	130
	Height	208
Energy density	Wh/kg	145
	Wh/l	328

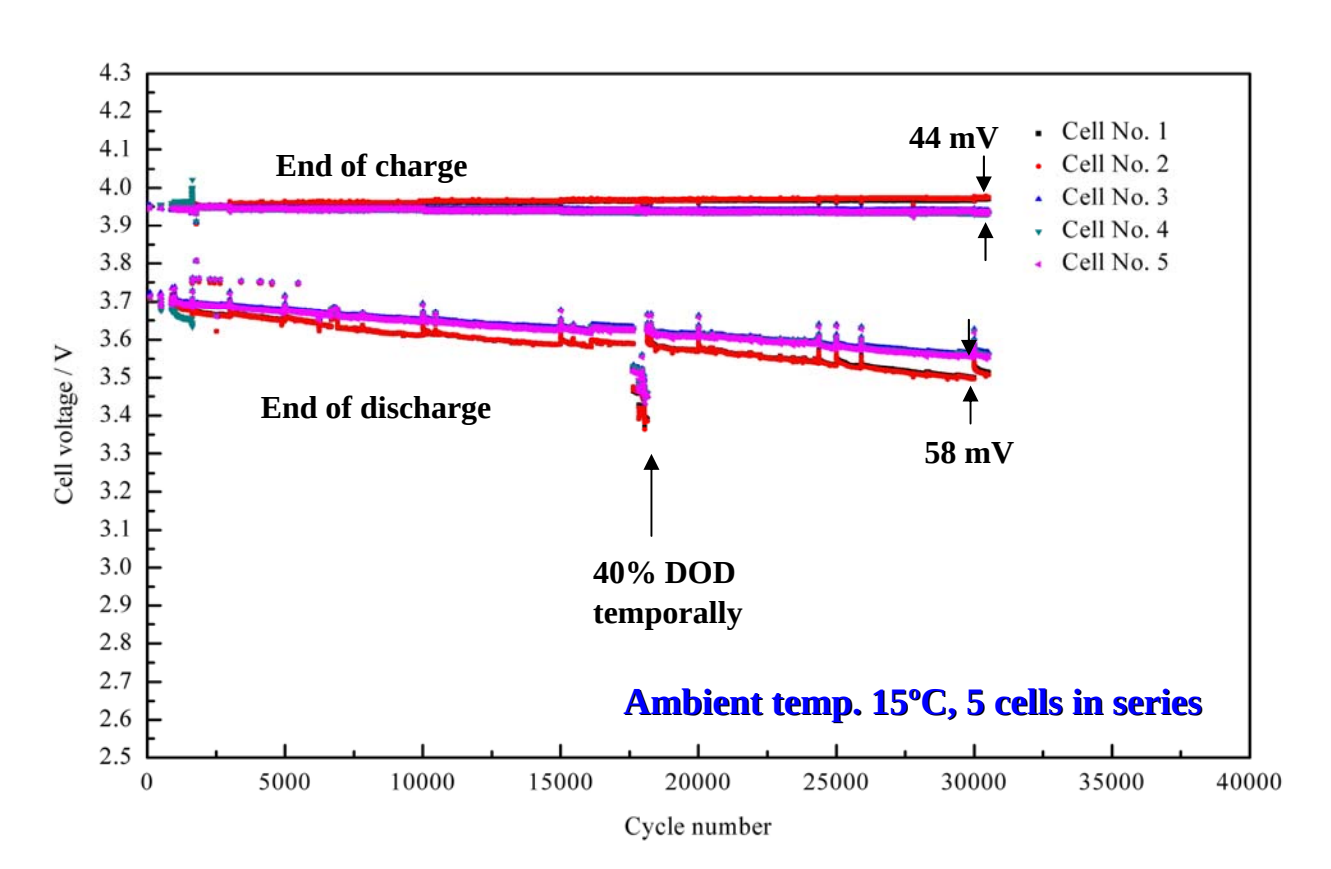
(1) Typical life performance

LEO simulation testing: 40% DOD



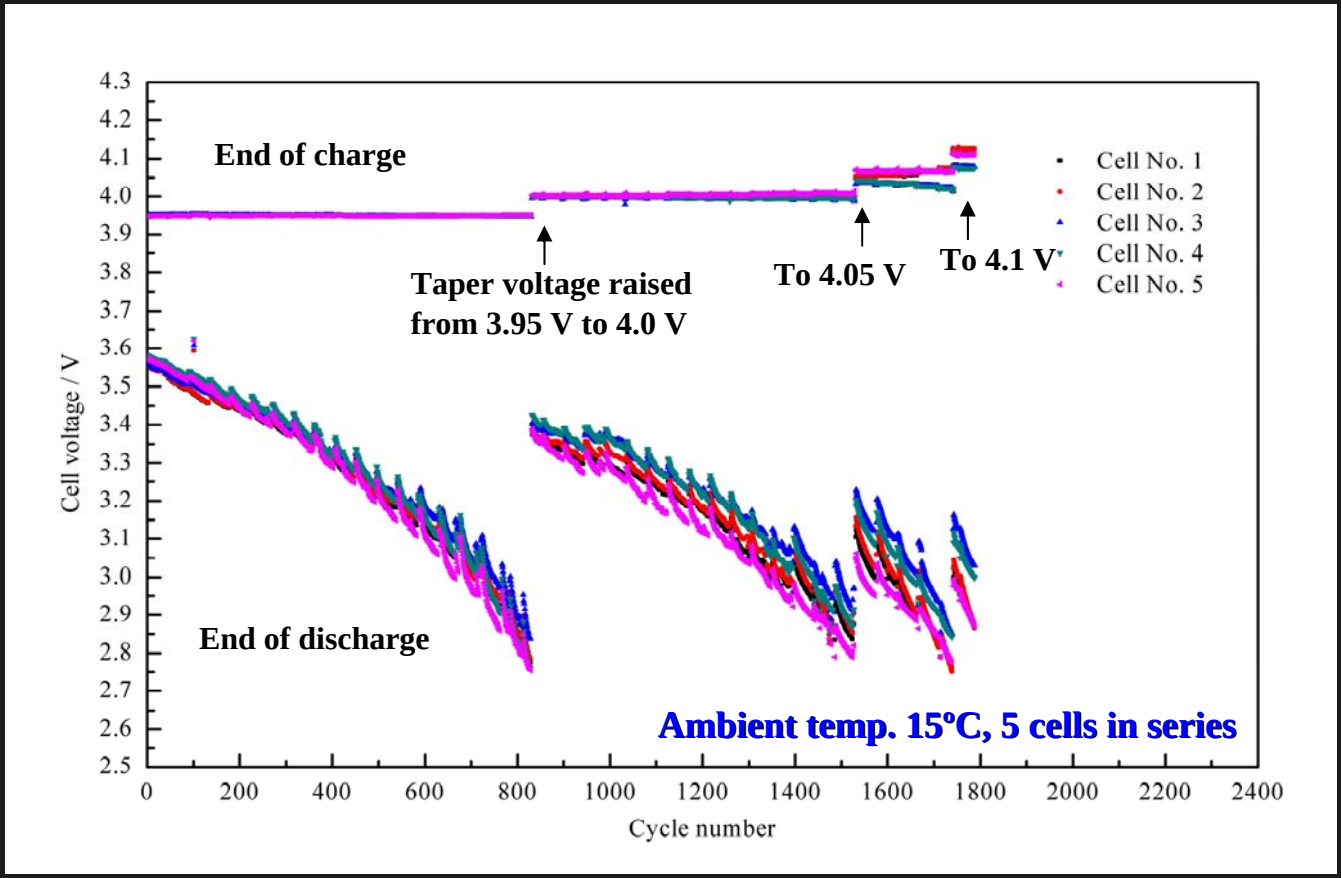
(1) Typical life performance

LEO simulation testing: 25% DOD



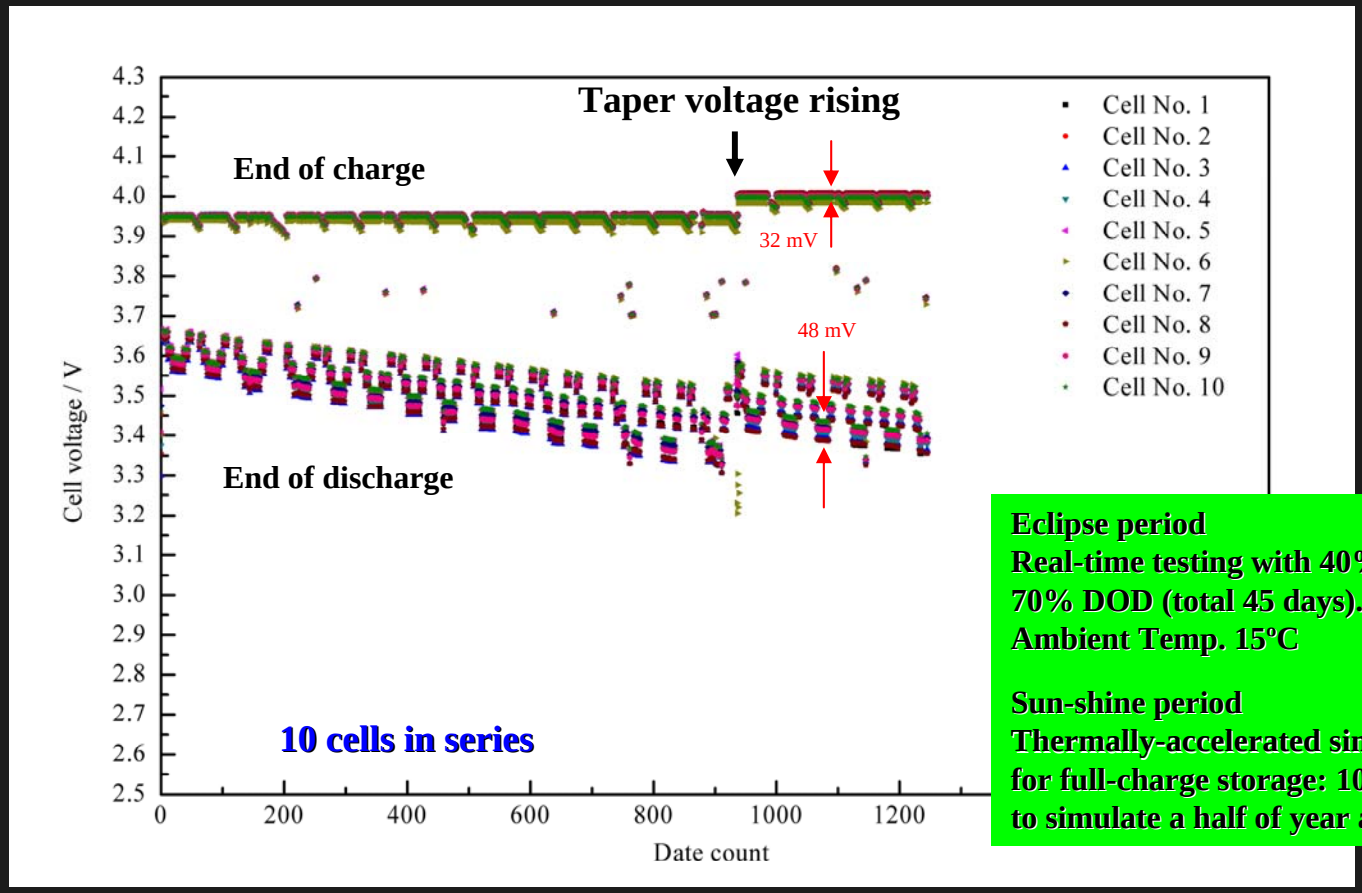
(1) Typical life performance

GEO simulation testing: 80% DOD



(1) Typical life performance

GEO simulation testing: max. 70% DOD



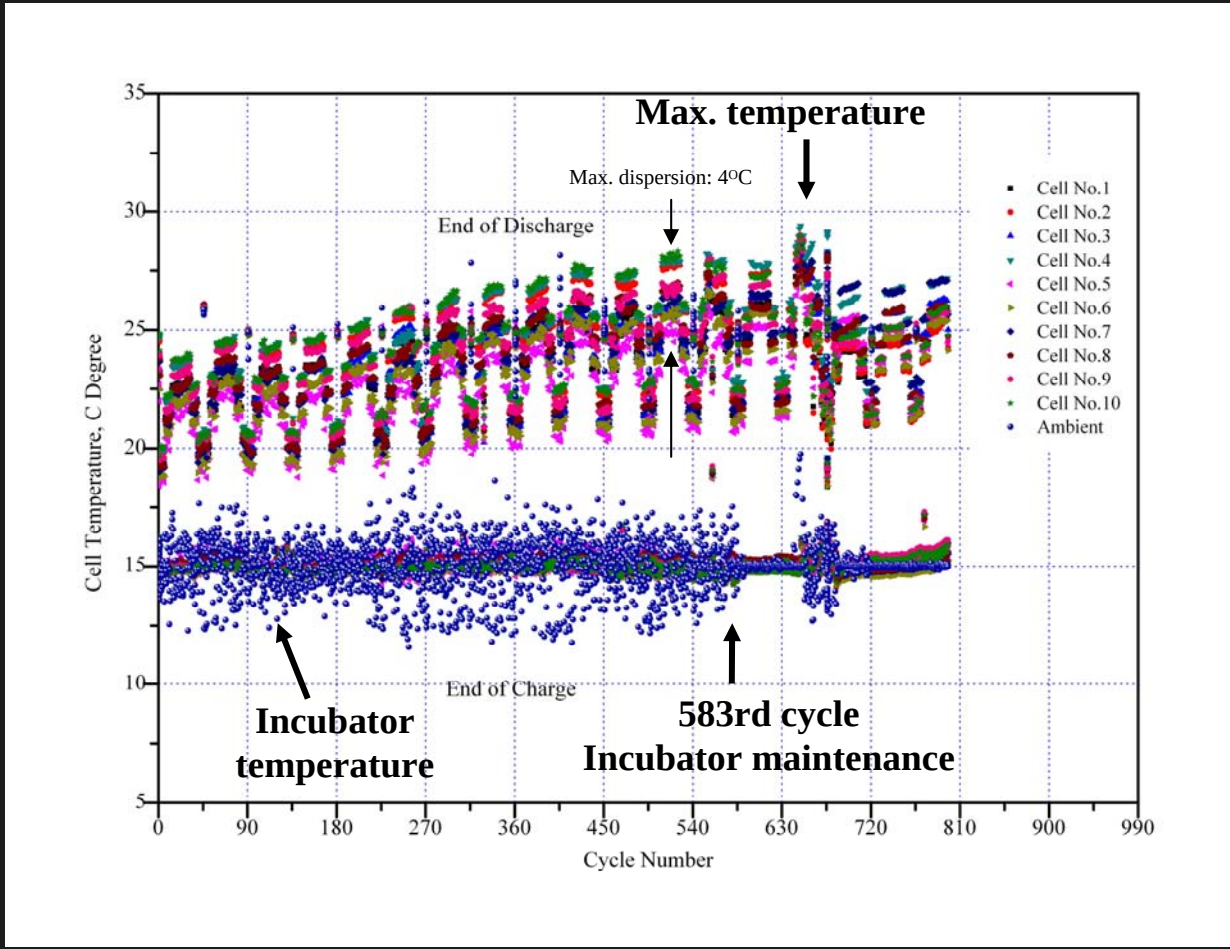
Eclipse period
Real-time testing with 40%, 60%, 70% DOD (total 45 days).
Ambient Temp. 15ºC

Sun-shine period
Thermally-accelerated simulation for full-charge storage: 10 days at 25ºC to simulate a half of year at 0ºC

(Correspond to 10 years operation)

Temperature history

Cell temperature in eclipse period



Showing only cyclic change in eclipse period

(1) Typical life performance

Summary

Large Lithium-ion cells evaluated at JAXA
with $LiCoO_2$ cathode and graphite anode

Meet the general requirements for LEO and GEO missions

1) high voltage retention
2) small cell voltage dispersion
3) low cell-temperature rising

(2) High-rate design

Design concept

Impedance increase with cycling is responsible for performance fading of a lithium-ion cell with $LiCoO_2$ cathode in our know-ledge. To improve cycle-life performance of the cell, we should suppress cell impedance by

- increasing electrode surface area
- decreasing electrode thickness.

(2) High-rate design

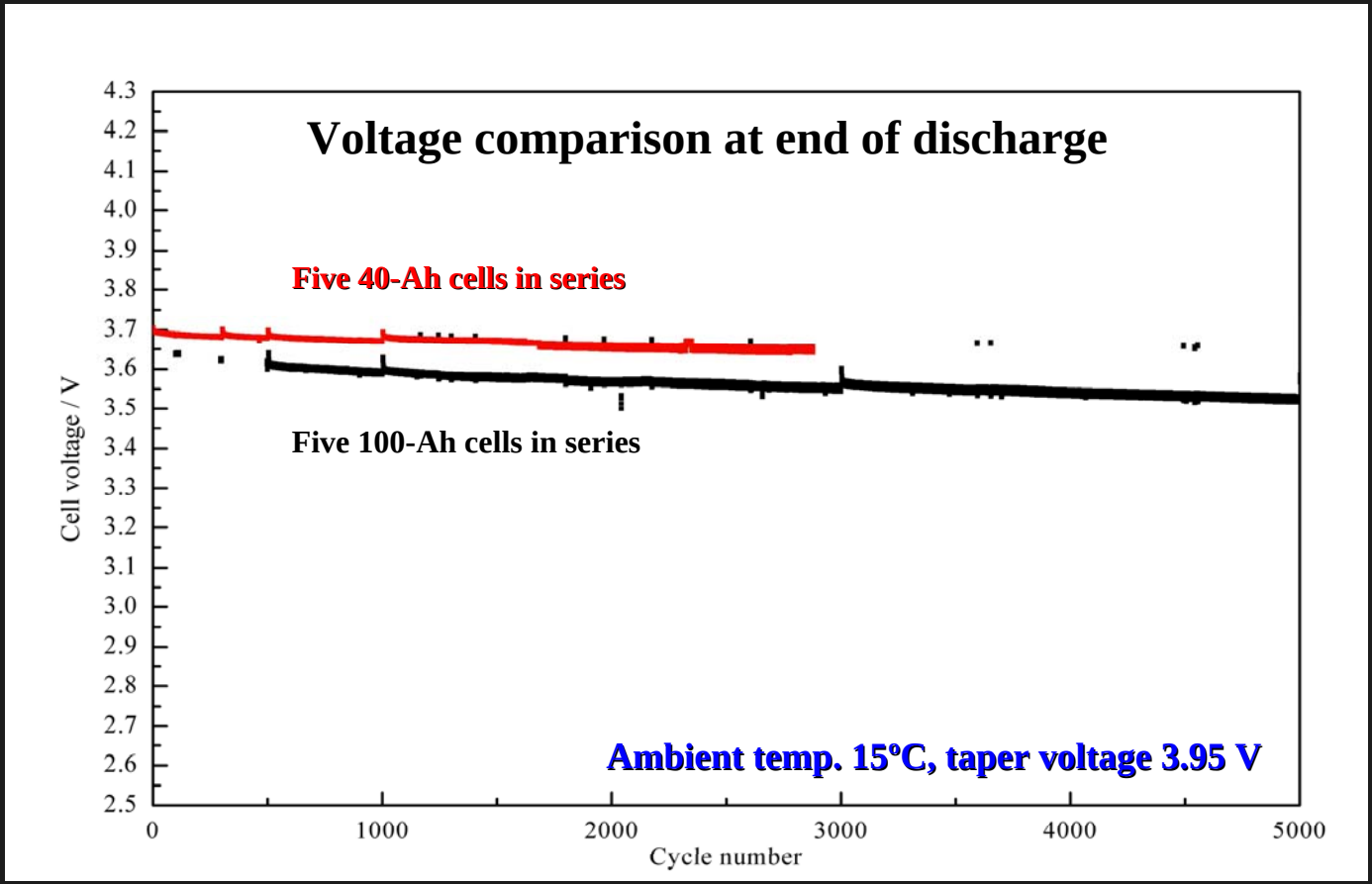
40-Ah cell with graphite anode and $LiCoO_2$ cathode: thinner electrode layer than that of 100-Ah cell

Manufactured by
GS-Yuasa Technology Ltd.

Cell type		Elliptic cylinder
Cathode		$LiCoO_2$
Anode		Graphite
Capacity	Rated	40
	Nominal	45
Nominal voltage, V		3.7
Weight, g		1,500
Dimensions, mm	Width	50
	Length	130
	Height	123
Energy density	Wh/kg	111
	Wh/l	

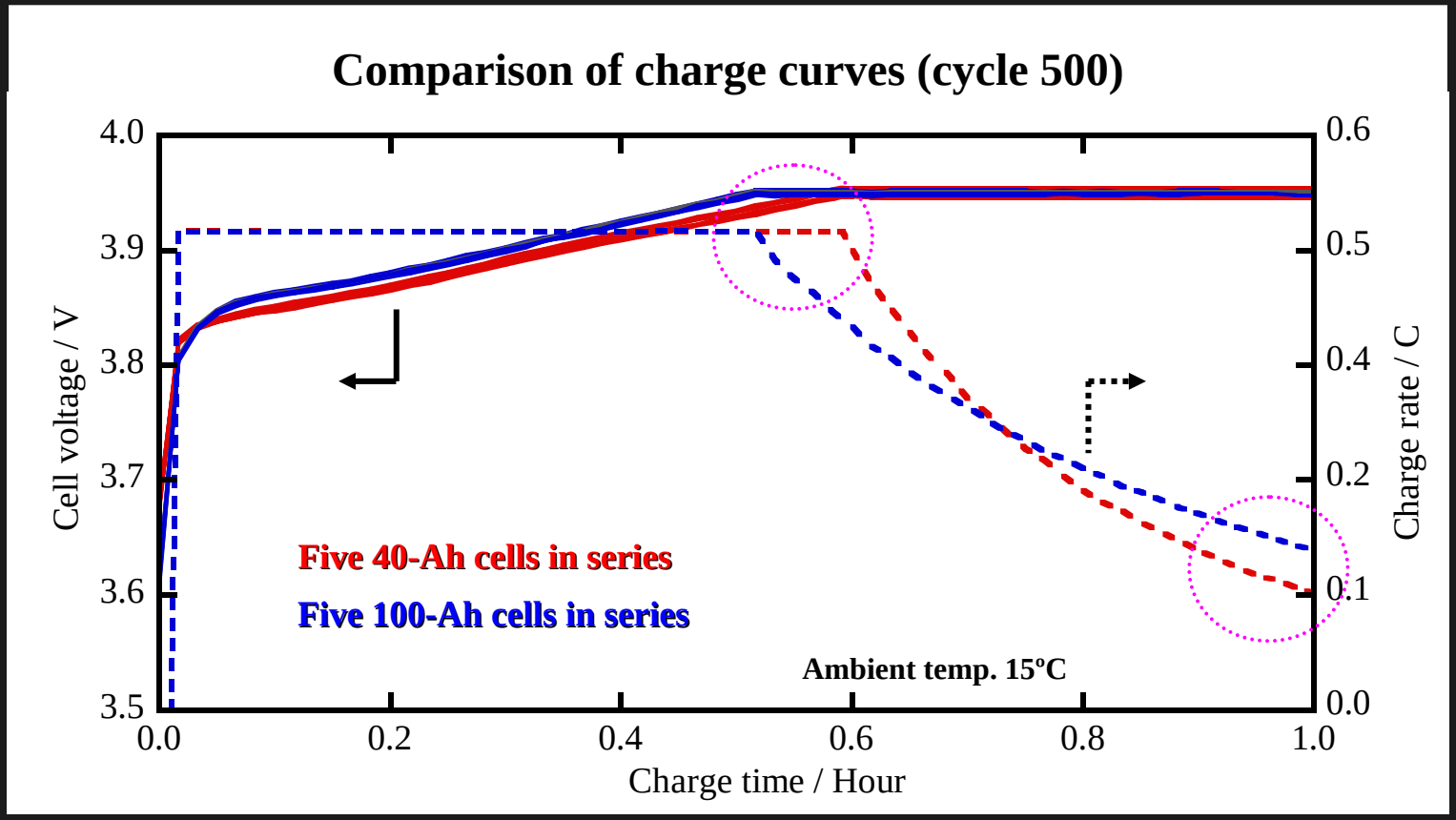
(2) High-rate design

LEO simulation testing: 40% DOD



(2) High-rate design

LEO simulation testing: 40% DOD



(2) High-rate design

Summary

High-rate designed lithium-ion cells
with $LiCoO_2$ cathode and graphite anode

Promising for LEO operation
due to slow impedance increase with cycling

(3) Alternative cathode materials

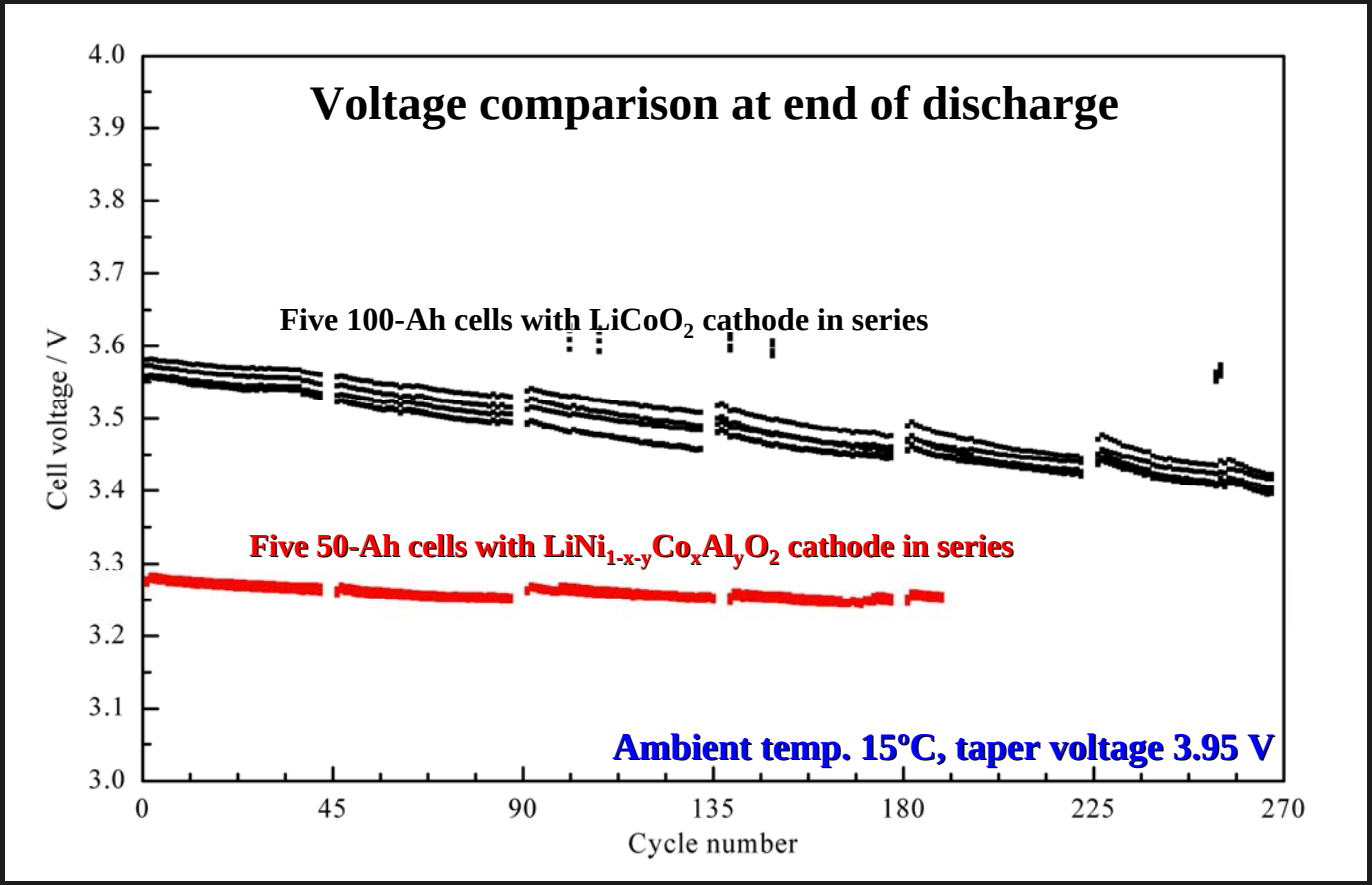
50-Ah cell with graphite anode and $LiNi_{1-x-y}Co_xAl_yO_2$ cathode

Manufactured by
GS-Yuasa Technology Ltd.

Cell type		Elliptic cylinder
Cathode		$LiNi_{1-x-y}Co_xAl_yO_2$
Anode		Graphite
Capacity	Rated	50
	Nominal	53
Nominal voltage, V		3.6
Weight, g		1,400
Dimensions, mm	Width	52
	Length	130
	Height	123
Energy density	Wh/kg	136
	Wh/l	254

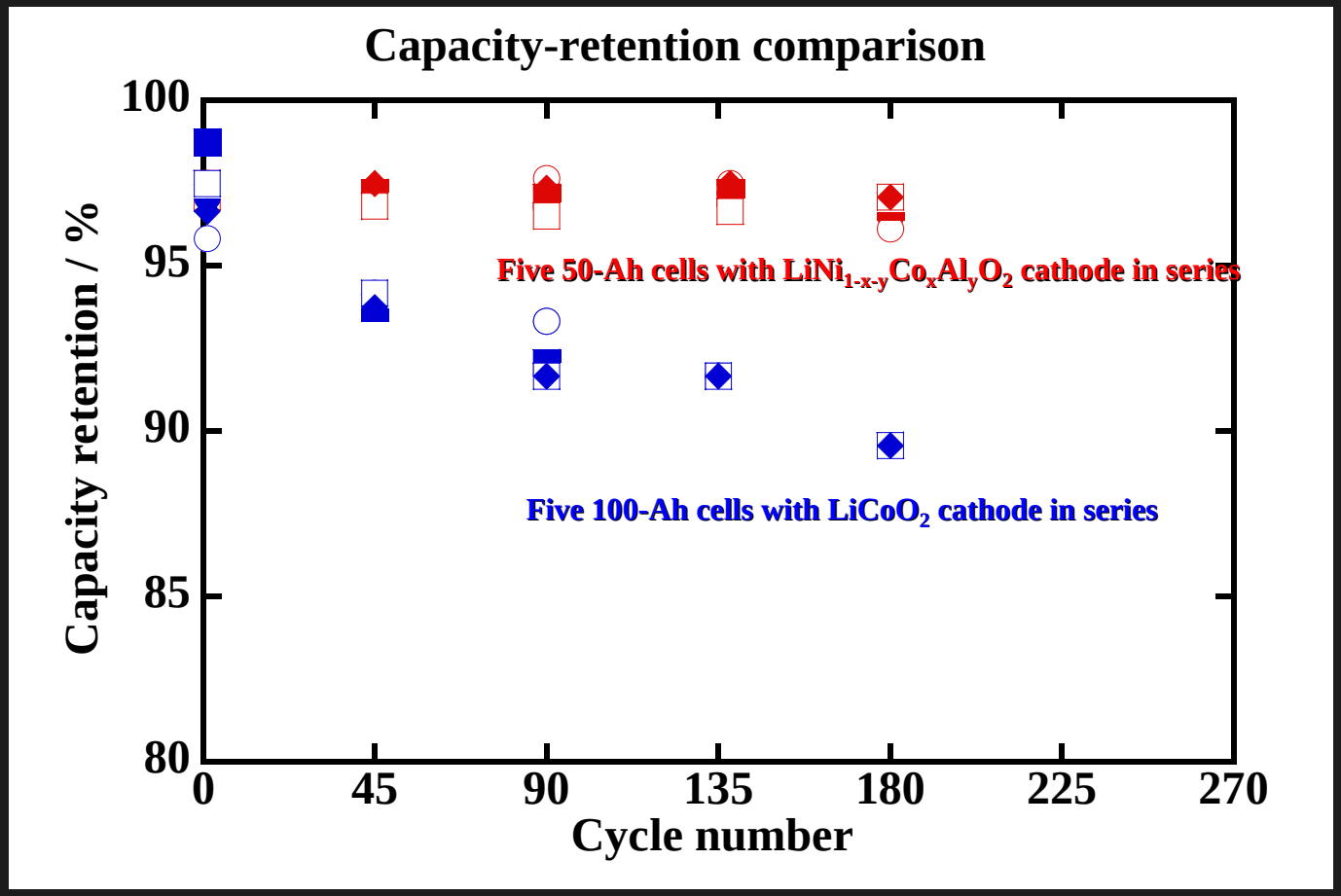
(3) Alternative cathode materials

GEO simulation testing: 80% DOD



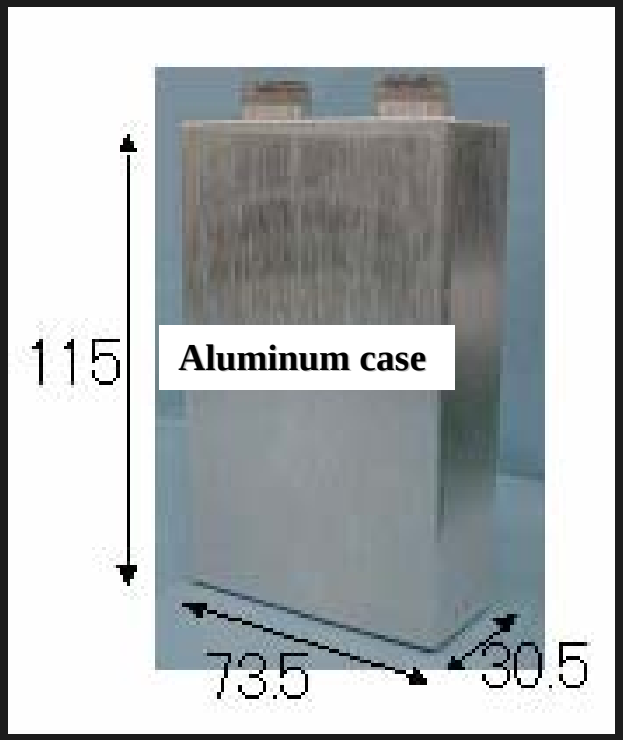
(3) Alternative cathode materials

GEO simulation testing: 80% DOD



(3) Alternative cathode materials

14.6-Ah cell with graphite anode and $LiMn_2O_4$ cathode

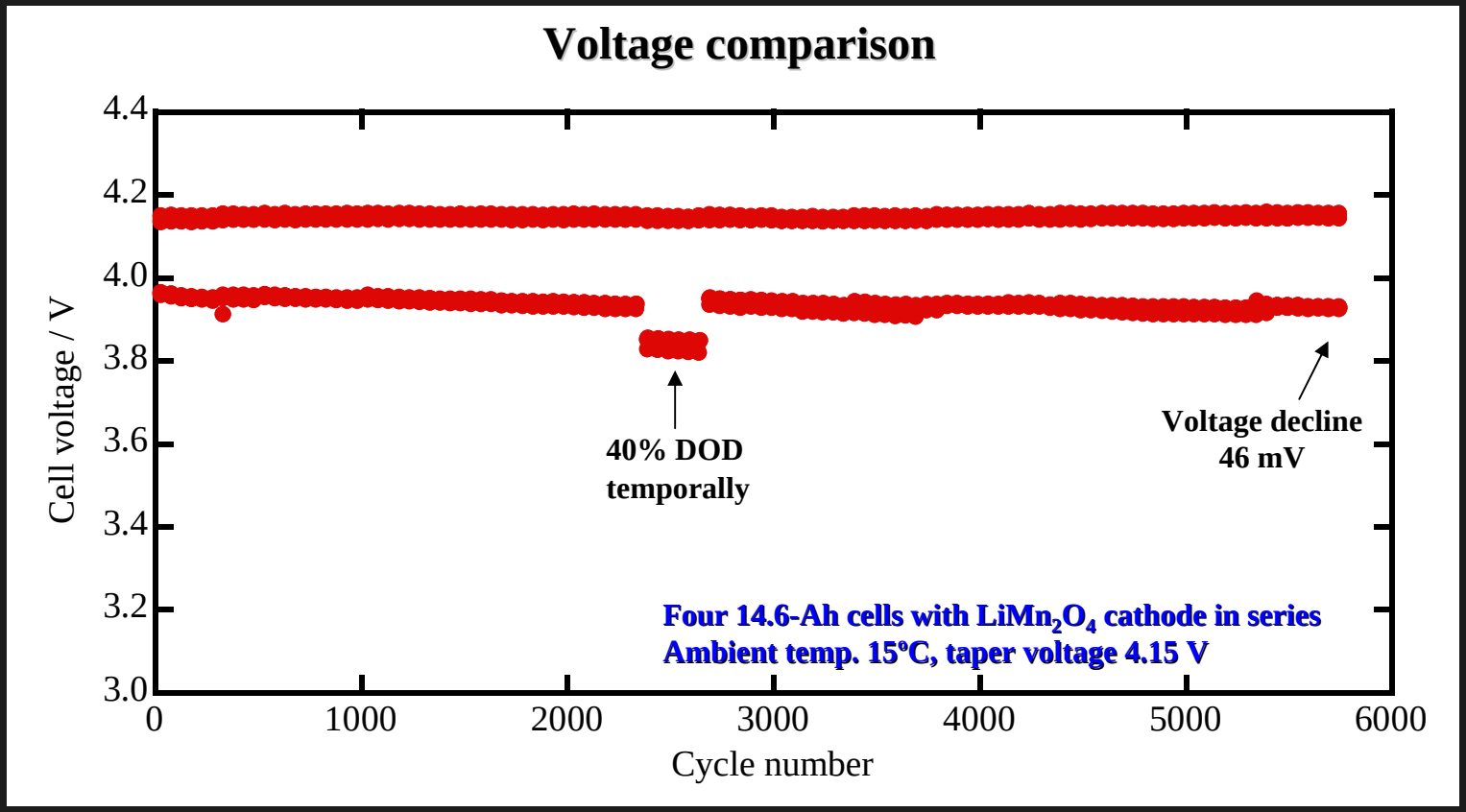


Manufactured by
Mitsubishi Heavy Industries, LTD.

Cell type		Prismatic
Cathode		$LiMn_2O_4$
Anode		Graphite
Capacity	Rated	14.6
	Nominal	15.5
Nominal voltage, V		3.87
Weight, g		570
Dimensions, mm	Width	30.5
	Length	73.5
	Height	115
Energy density	Wh/kg	105
	Wh/l	233

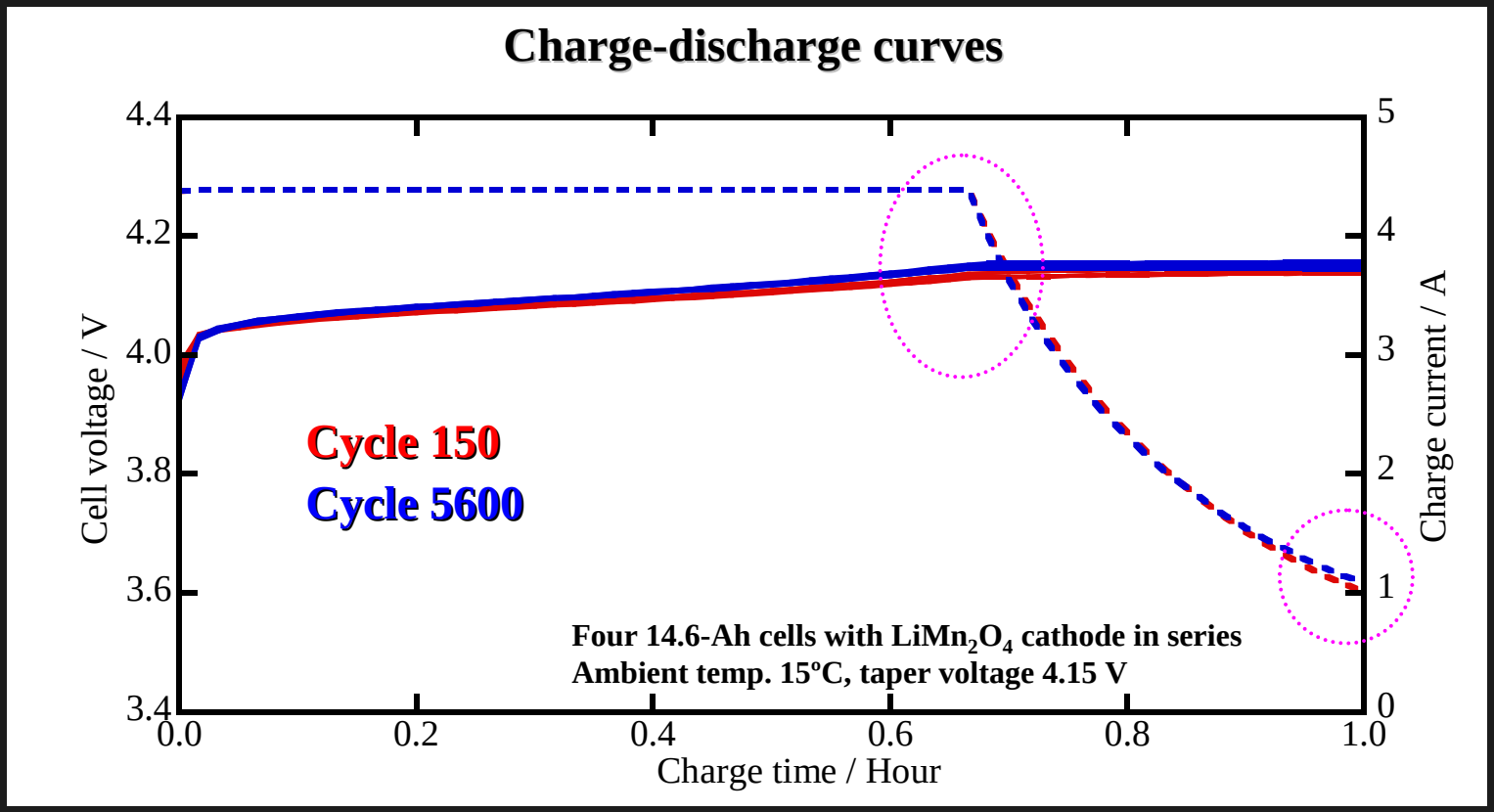
(3) Alternative cathode materials

LEO simulation testing: 25% DOD



(3) Alternative cathode materials

LEO simulation testing: 25% DOD



(3) Alternative cathode materials

Summary

Lithium-ion cells

with $LiNi_{1-x-y}Co_xAl_yO_2$ ($LiMn_2O_4$) cathode material

Expected to be a candidate for one of the alternative of $LiCoO_2$ cathode for GEO (LEO) mission

Prospect

Large capacity Lithium-ion cells

Under qualification for a few satellite- and rocket-projects at JAXA

(1) Continue on-ground real time cycle-life testing
(2) Optimize the operation conditions in a space environment
(3) Establish database with different electrode materials

Acknowledgments

GS Yuasa Technology (GYT/JSB)
Mitsubishi Electric Corporation (MELCO)
Mitsubishi Heavy Industries (MHI)
for
supplying of the battery and helpful discussions

Ryoei Technica Corporation
for
Technical support