Study on Commercially Available Lithium-Ion Cells for Small Satellites

Chisa Yamada, Hitoshi Naito, and Koichi Kibe,
Japan Aerospace Exploration Agency (JAXA)

1. Batteries for Small Satellites

- JAXA's Small Satellites and their Batteries
- Using Commercially Available Lithium-Ion Cells

2. Model Cell Selection and Database

- Electric Properties
- Tolerant Environmental Conditions

3. Selection Parameters and Life Cycling Test

- Uniform Cell Selection
- Life Cycling test

4. Conclusion

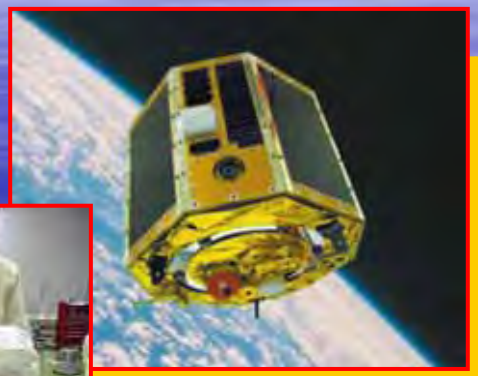
1. Batteries for Small Satellites

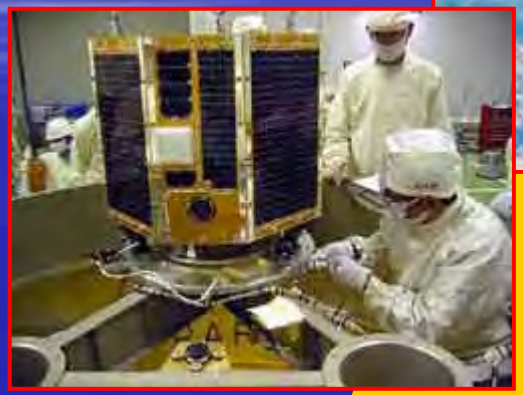
宇宙航空研究開発機構
Japan Aerospace Exploration Agency

- JAXA's Small Satellites and their Batteries
- Using Commercially Available Lithium-Ion Cells

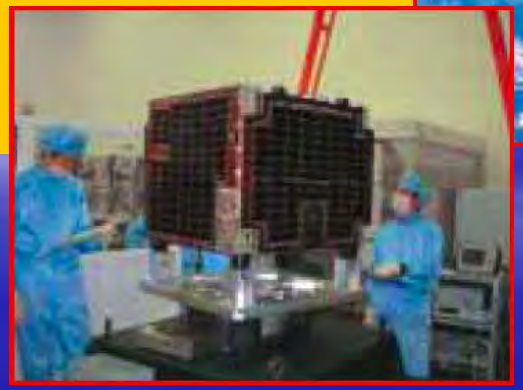
JAXA's Small Satellites

2002
μ-LabSAT

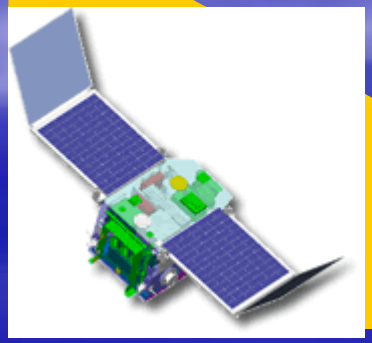




Ni-MH Battery

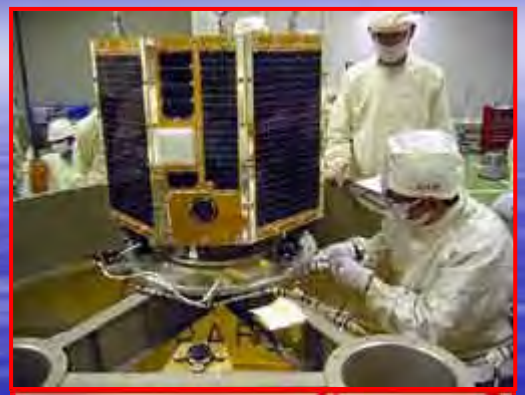


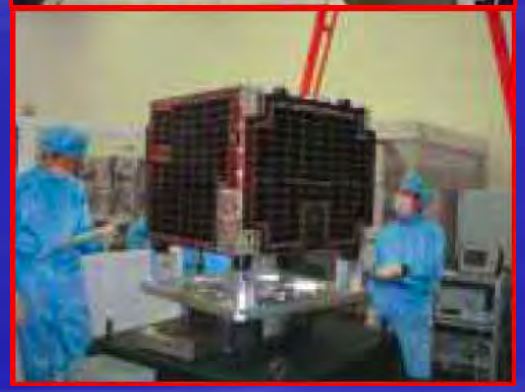
2009
SDS-1



2005
INDEX
(Li-ion-BAT)

Batteries for Small Satellites





For Small Satellites

→ Commercially Available Cells

- easiness of manufacturing
- inexpensive

etc...

We need to...

- select the model cell fulfilled with requirements of power supply system in the satellite
- select the cell with even performances

Purpose of this study

For Next Small Satellites (with enlarged missions & power),

→ Lithium-ion battery (with higher energy density)

To use commercially available lithium-ion cells on small satellites;

- model cell selection
  basic characteristics of various cells
  → database
- uniform cell selection
  which parameter causes cells' variations most?

were determined.

2. Model Cell Selection Database

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

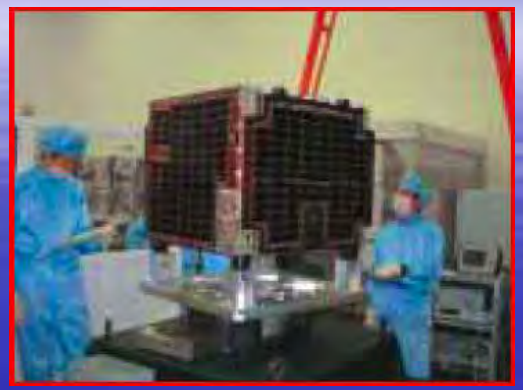
- Model Cell Selection of Commercially Available Lithium-Ion Cells
- Electric Properties
- Tolerant Environmental Conditions

Model Cell Selection Database

cells

in series
in parallel

batteries



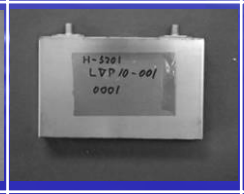
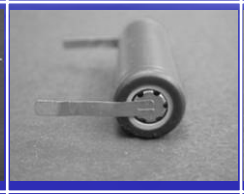
small satellite

need basic characteristics

designed to make missions performable

We studied the basic characteristics of 7 kinds of the commercially available lithium-ion cells, and made them to the database.

Samples

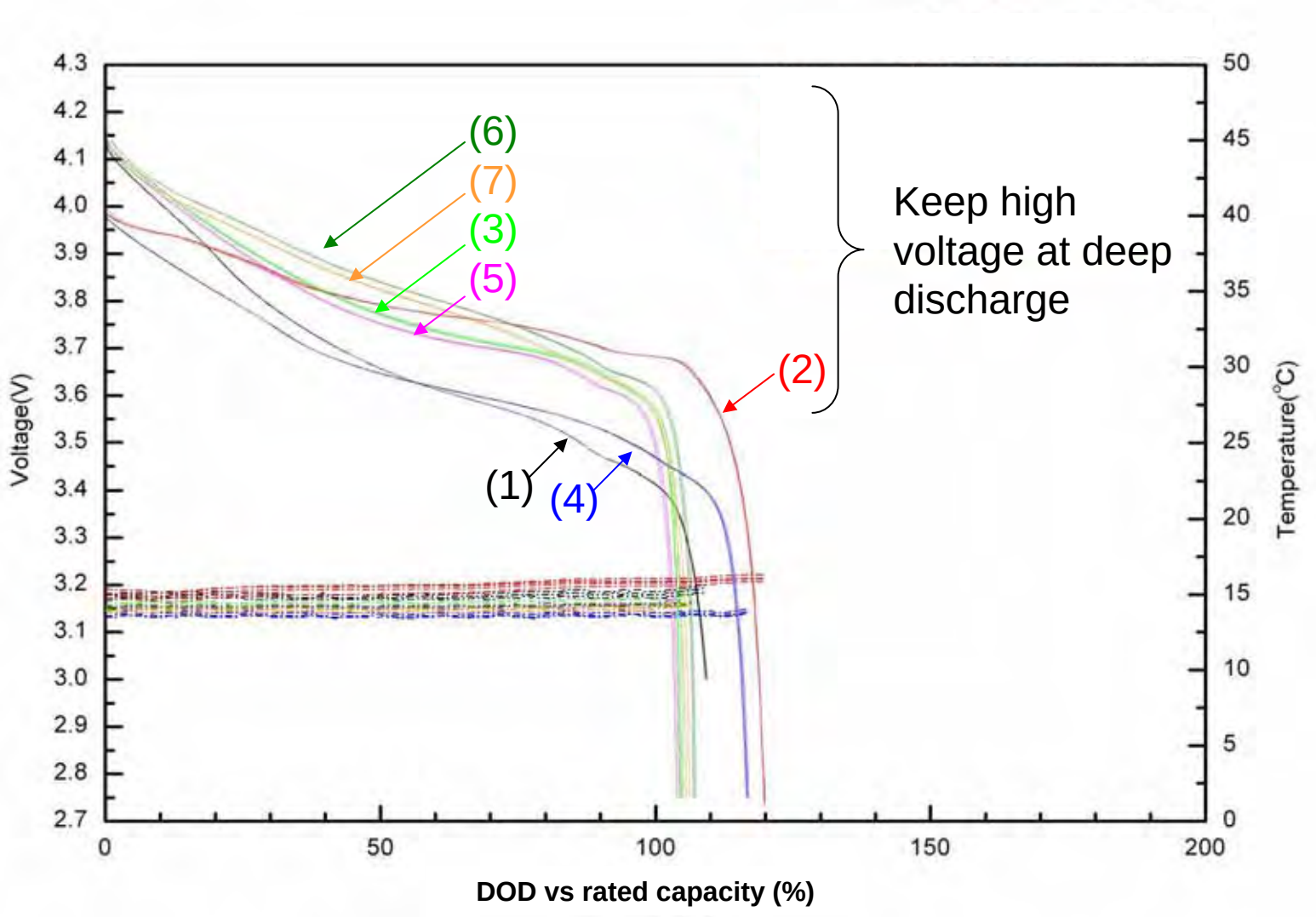
Samples	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Rated Capacity	15 Ah	10 Ah	2500 mAh	1100 mAh	1880 mAh	1300 mAh	2700 mAh
Shape							
Size / mm	6.5*148*215	21*130*80	Φ18*65	Φ18*65	10.5*34*49	4*52*69	6*44*96
Weight	530 g	490 g	47.5 g	41.5 g	38.5 g	28.5 g	57.5 g
Average Voltage	3.6 V	3.7 V	3.7 V	3.7 V	3.7 V	3.7 V	3.7 V
Electrolyte	Liquid	Liquid	Liquid	Liquid	Liquid	Gel	Gel
Container	rectangular, stainless	rectangular, stainless	cylindrical, stainless	cylindrical, stainless	rectangular, aluminium	Laminated, aluminium	Laminated, aluminium
No. of cells to make 11 Ah - 28 V- system	8 (8s1p)	16 (8s2p)	48 (8s6p)	80 (8s10p)	48 (8s6p)	80 (8s10p)	32 (8s4p)
AC impedance (1 kHz) measured	1.9 mΩ	1.2 mΩ	45 mΩ	27 mΩ	65 mΩ	34 mΩ	24 mΩ

Electric Properties

Capacity test	5, 15, 25 ^{o}C 0.2C, 0.5C discharge
LEO cycling test	DOD25%, 40%
High-rate discharge	1.35C (1 min), 0.75C (5 min)
Self-discharge	72 hour

(3 cells each)

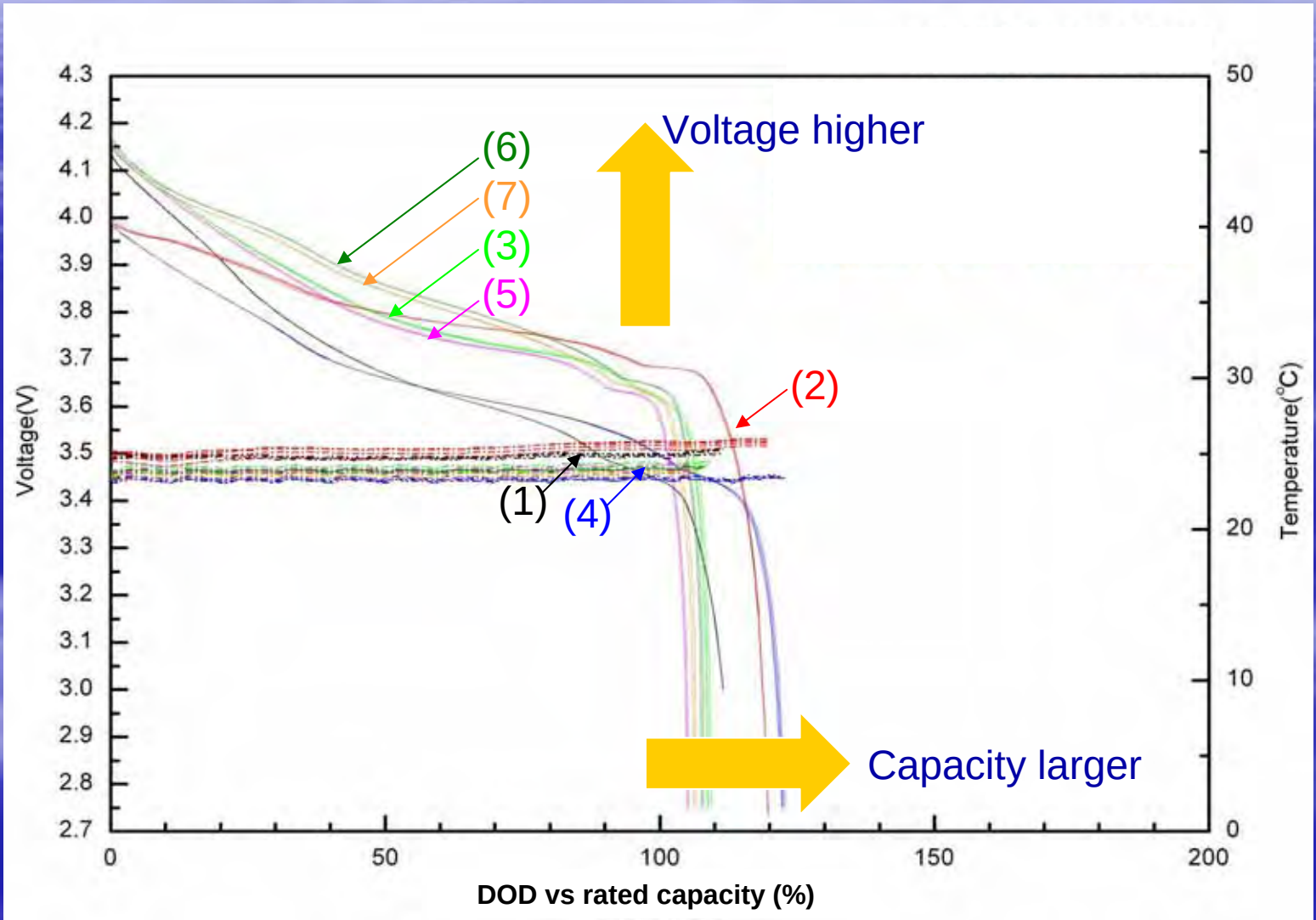
Capacity test (15°C, 0.2C)



Capacity test (25°C, 0.2C)

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

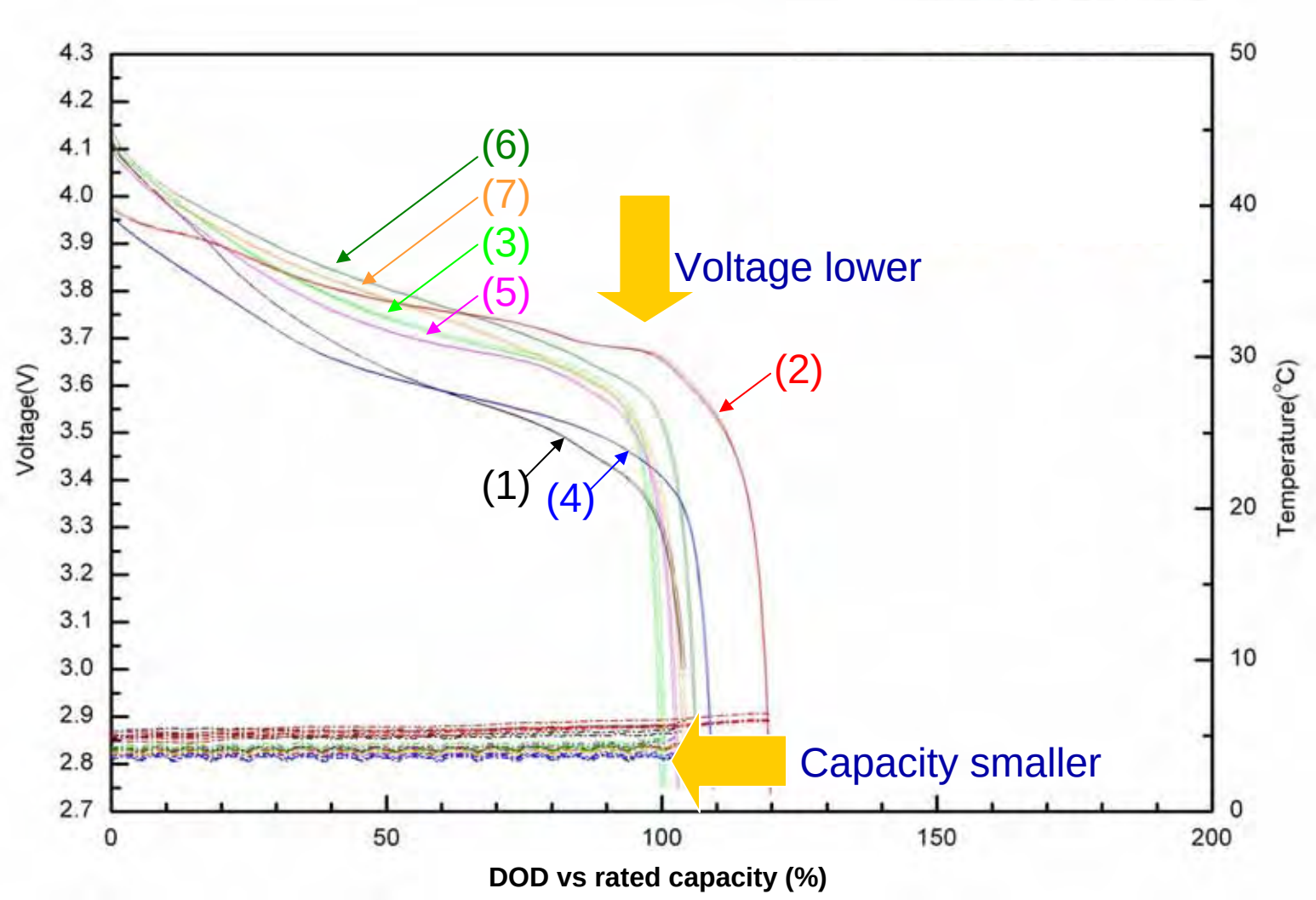
Discharged at relatively high temperature



Capacity test (5°C, 0.2C)

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

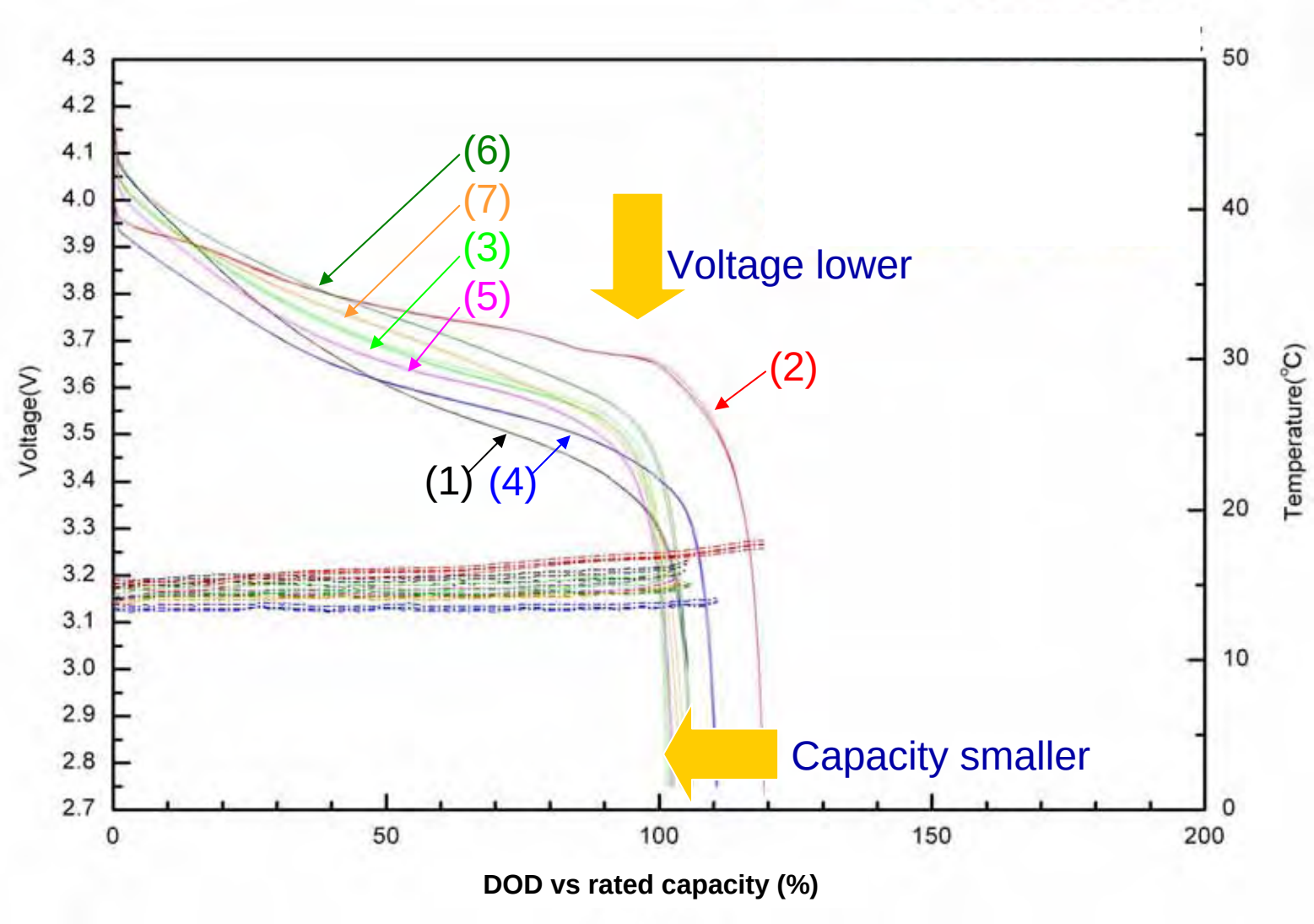
Discharged at relatively low temperature



Capacity test (15°C, 0.5C)

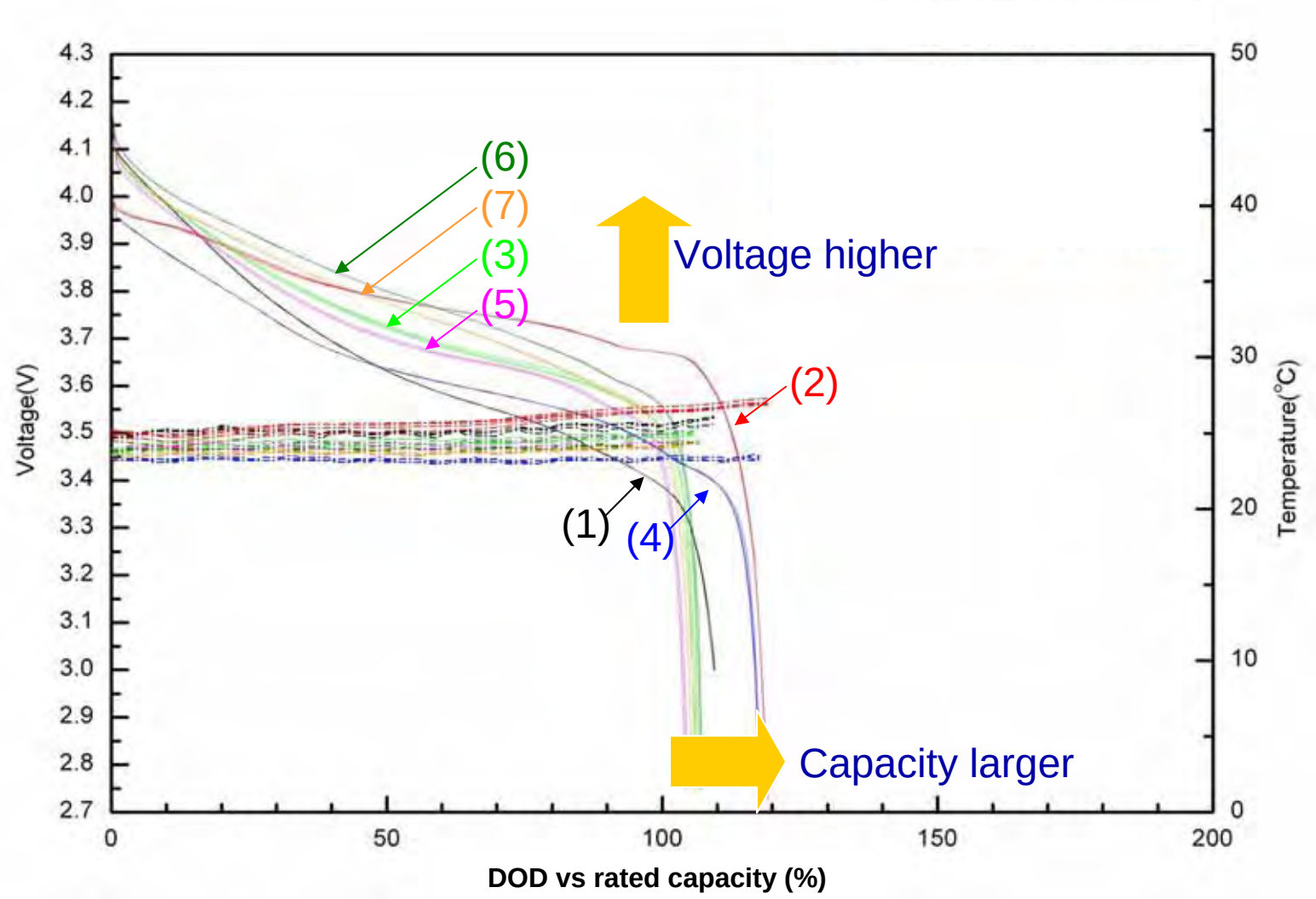
宇宙航空研究開発機構
Japan Aerospace Exploration Agency

Discharged at high-rate



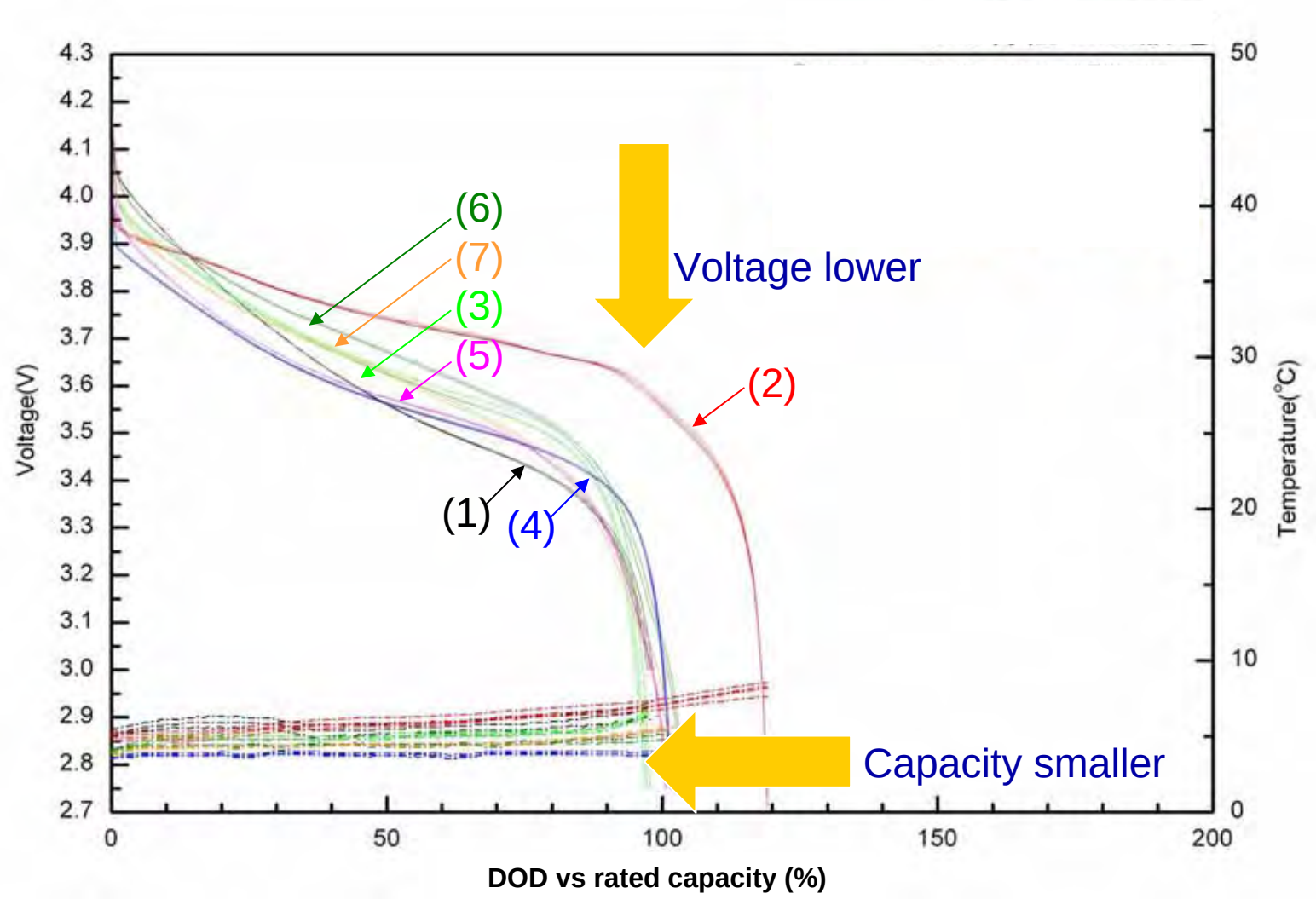
Capacity test (25°C, 0.5C)

Discharged at relatively high temperature and high-rate



Capacity test (5°C, 0.5C)

Discharged at relatively low temperature and high-rate



Summary of Capacity Test

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

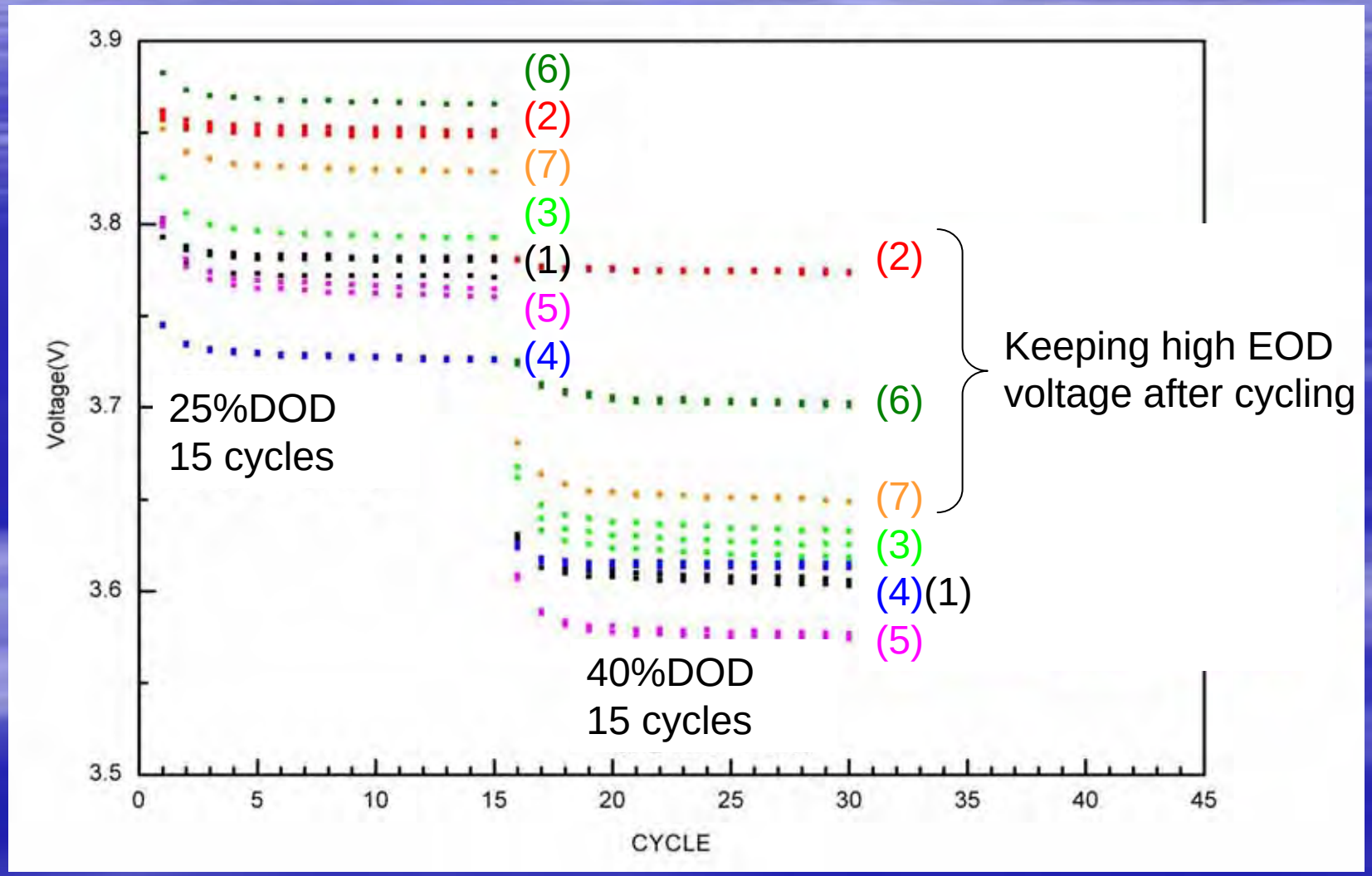
	15°C		25°C		5°C	
	0.2C discharge	0.5C discharge	0.2C discharge	0.5C discharge	0.2C discharge	0.5C discharge
(1)	109	105	112	110	104	98
(2)	120	119	120	119	120	119
(3)	105	102	109	106	100	99
(4)	115	111	122	118	109	102
(5)	104	103	105	104	103	101
(6)	107	106	108	107	107	105
(7)	106	105	107	106	105	104

Actual Capacity (%)
Rated Capacity

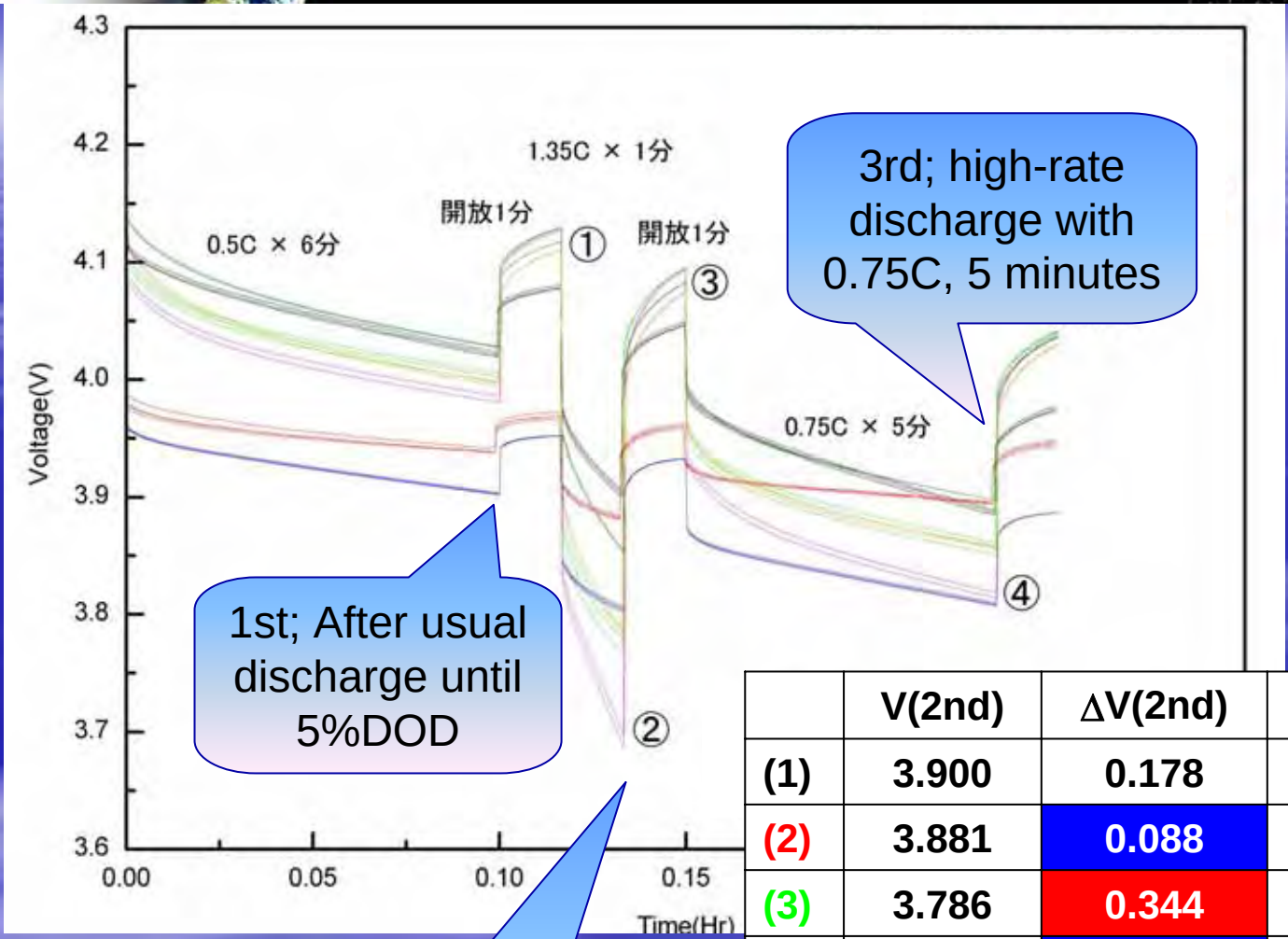
LEO Cycling test (15°C)

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

Charge 60 minutes / Discharge 30 minutes



High-rate Discharge



3rd; high-rate discharge with 0.75C, 5 minutes

1st; After usual discharge until 5%DOD

2nd; high-rate discharge with 1.35C, 1 minute

	V(2nd)	ΔV(2nd)	V(3rd)	ΔV(3rd)
(1)	3.900	0.178	3.885	0.161
(2)	3.881	0.088	3.894	0.066
(3)	3.786	0.344	3.861	0.235
(4)	3.806	0.147	3.810	0.123
(5)	3.687	0.440	3.814	0.279
(6)	3.854	0.263	3.897	0.186
(7)	3.781	0.330	3.856	0.219

Self-Discharge

Samples	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Capacity remained after 72 h (%)	**99.7**	**99.0**	**99.6**	**99.2**	**99.5**	**98.6**	**99.3**
Self-discharge rate (%/day)	**0.098**	**0.332**	**0.143**	**0.273**	**0.173**	**0.483**	**0.235**

Tolerant Environmental Conditions

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

Strong Vibration

Ultra High
Vacuum

Vibration test

sine wave vibration test
random vibration test
} each x, y, z-axes of cells

Checkout...
- appearance
- electric properties (capacity test, self-discharge)

before and after the vibration tests.

All the 7 kind of cells;
No significant differences

Z-axis sine wave vibration test

Decompression test

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

Kept at 5 Pa for 6 hours, detected elements below;

samples	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Ethyl alcohol エチルアルコール	4.37	-	*	*	-	-	*
Melthyl alcohol メチルアルコール	3.66	-	*	-	-	-	-
Isopropyl alcohol イソプロピルアルコール	-	*	*	*	*	-	*
n-Butyl alcohol n-ブチルアルコール	-	-	*	*	-	*	-
Benzene ベンゼン	-	*	*	*	-	*	*
Toluene トルエン	-	-	*	*	-	*	-
C11 aromatic hydrocarbon C11 アロマティックハイドロカーボン	-	-	5.17	0.961	0.959	*	*
Cyclohexylbenzene シクロヘキシルベンゼン			-	0.393	-	-	1.07
Ethyl methyl carbonate エチルメチルカーボネート	19.7	-	*	*	*	*	13.6
Diethyl carbonate ジエチルカーボネート	*	-	*	2.91	6.79	1.36	4.66
Dimethyl carbonate ジメチルカーボネート	-	-	21.2	13.3	*	*	*
2-Butanone oxime 2-ブタノンオキシム	-	-	-	*	-	-	-
Decamethylcyclopentasiloxane デカメチルシクロペンタシロキサン	*	0.709	0.649	0.953	0.889	0.789	0.602
Dodecamethylcyclohexasiloxane ドデカメチルシクロヘキサシロキサン	*	0.382	0.375	*	-	0.431	0.390
Dodecamethylpentasiloxane ドデカメチルペンタシロキサン	*	*	*	*	*	*	0.350
Octamethycyclotetrasiloxane オクタメチルシクロテトラシロキサン	*	*	*	0.498	1.08	*	-
Trimethylsilanol トリメチルシラノール	-	*	-	-	*	-	-
Hexamethylcyclotrisiloxane ヘキサメチルシクロトリシロキサン	*	*	-	-	*	-	-
Electrolyte elements	a little	trace	a little	a little	tiny	tiny	tiny

Electrolyte elements

No significant differences between before and after the decompression test

Cell Model Selection

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

DATABASE

Uniform Electric Properties
(Voltage, Capacity, Self-Discharge)

Tolerant Environmental Conditions
(Vibration, Ultra High Vacuum)

Characteristics
(Weight, impedance, specifications)

***	***	****
***	**	*****
*	***	**

Select Model Cell
fulfilled with satellite's requirements

For next small satellite, SDS-3, we selected cell (7).

3. Selection Parameters and Life Cycling Test

- Uniform Cell Selection
- Life Cycling test

Uniform Cell Selection

cells

in series
in parallel

batteries

To maintain high performances of batteries long enough, we have to select cells with even performances

Parameter Comparison

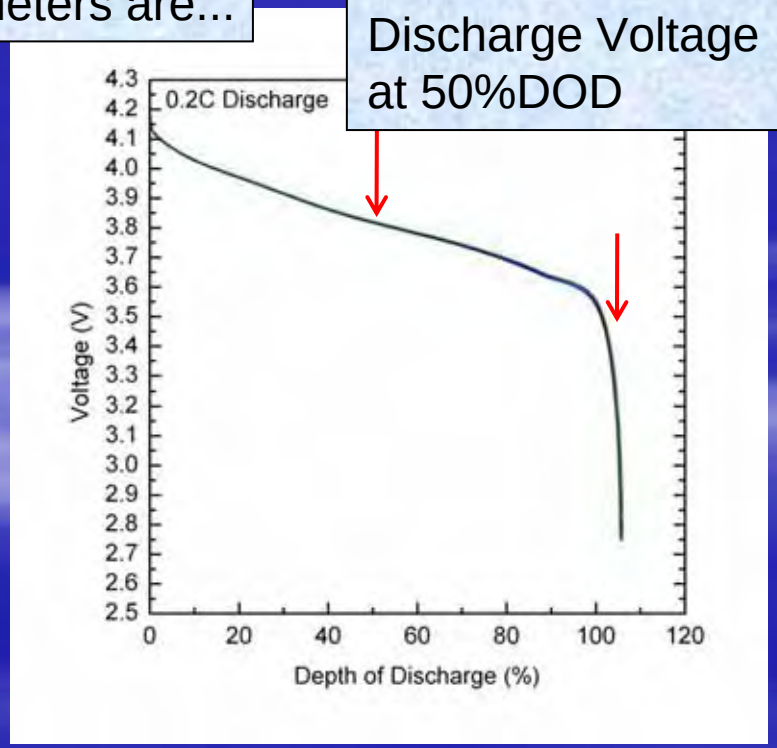
Parameter Comparison Test; 12 cells of (7)

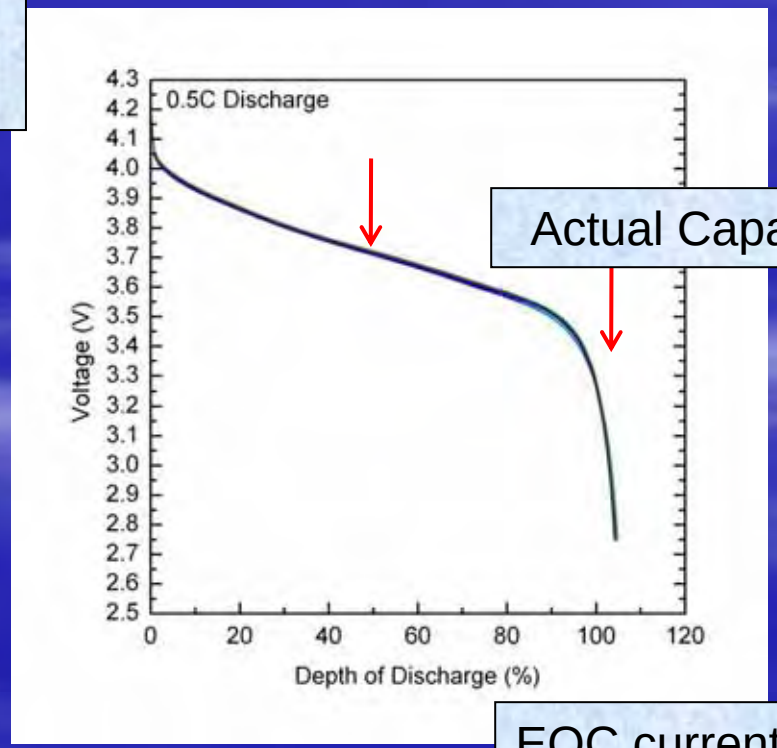
Decompression test: All passed
Electric Properties: Capacity test, Self-Discharge, etc.
Characteristics: Weight, Impedance, etc.

Ex) Capacity test; discharging curve

Parameters are...

Discharge Voltage at 50%DOD





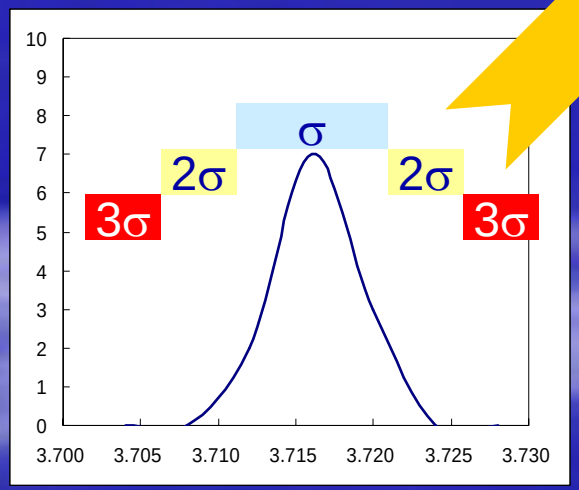
Actual Capacity

EOC current, etc.

Parameter Comparison of Cell (7)

Result: Each parameter normally distributed

			0.2C放電特性			自己放電	0.5C放電特性			自己放電率								
Cell ID	S/N	Lot	EoCl / A	MoDV / V	Cap. /mAh	deltaV / V	EoCl / A	MoDV / V	Cap. /mAh	D-rate / % day-1	Weight / g	IMP / moh	Weight / g	IMP / moh	Weight / g	IMP / moh	DC / ohm
21	B11962	B	0.00148	3.820	2862.6	0.0051	0.00102	3.713	2828.9	0.251	54.40	23.58	54.39	23.35	-0.01	-0.23	0.132
22	B12025	B	0.00103	3.821	2855.5	0.0052	0.00125	3.716	2823.1	0.261	54.47	23.54	54.48	23.82	0.01	0.28	0.130
23	B12245	B	0.00140	3.822	2858.8	0.0055	0.00079	3.720	2824.8	0.259	54.41	23.62	54.42	23.74	0.01	0.12	0.126
24	B12567	B	0.00070	3.816	2848.3	0.0052	0.00097	3.708	2818.3	0.227	54.97	23.82	54.95	24.00	-0.02	0.18	0.134
25	B12706	B	0.00103	3.821	2859.3	0.0057	0.00113	3.716	2825.9	0.273	54.26	23.35	54.26	23.89	0.00	0.54	0.130
26	B12925	B	0.00124	3.821	2855.9	0.0056	0.00146	3.716	2820.1	0.268	54.47	23.51	54.46	23.59	-0.01	0.08	0.130
27	B12997	B	0.00080	3.821	2851.8	0.0056	0.00127	3.716	2813.7	0.258	54.31	23.28	54.30	23.77	-0.01	0.49	0.130
28	B13421	B	0.00122	3.820	2853.8	0.0053	0.00133	3.714	2814.7	0.204	54.47	23.51	54.47	23.90	0.00	0.39	0.130
29	B13440	B	0.00118	3.819	2849.2	0.006	0.00091	3.712	2812.7	0.255	54.41	23.11	54.41	23.40	0.00	0.29	0.132
30	B14090	B	0.00209	3.820	2849.2	0.0065	0.00205	3.716	2816.0	0.245	54.38	23.34	54.38	23.88	0.00	0.54	0.129
31	B14091	B	0.00100	3.822	2851.2	0.0055	0.00370	3.722	2818.2	0.242	54.45	23.10	54.44	23.43	-0.01	0.33	0.125
32	B14105	B	0.00000	3.822	2856.6	0.0061	0.00270	3.720	2822.5	0.249	54.54	23.47	54.53	23.45	-0.01	-0.02	0.125
	average		0.00120	3.820	2854.1	0.0055636	0.00144	3.715	2819.7	0.249	54.45	23.43	54.45	23.71	-0.004	0.27	0.130
	min		0.00070	3.816	2848.3	0.0051	0.00079	3.708	2812.7	0.204	54.26	23.10	54.26	23.35	-0.02	-0.23	0.125
	max		0.00209	3.822	2862.6	0.0065	0.00370	3.722	2828.9	0.273	54.97	23.82	54.95	24.00	0.01	0.54	0.134



1. Capacity
2. Impedance
3. Self-Discharge rate

Which parameter is most important?

Priority of Parameters

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

Parameters

- Capacity … traditionally emphasized
- Impedance
- Self-Discharge rate

} unable to ignore

Which parameter causes cells' variations most?

Verify with Life Cycling test

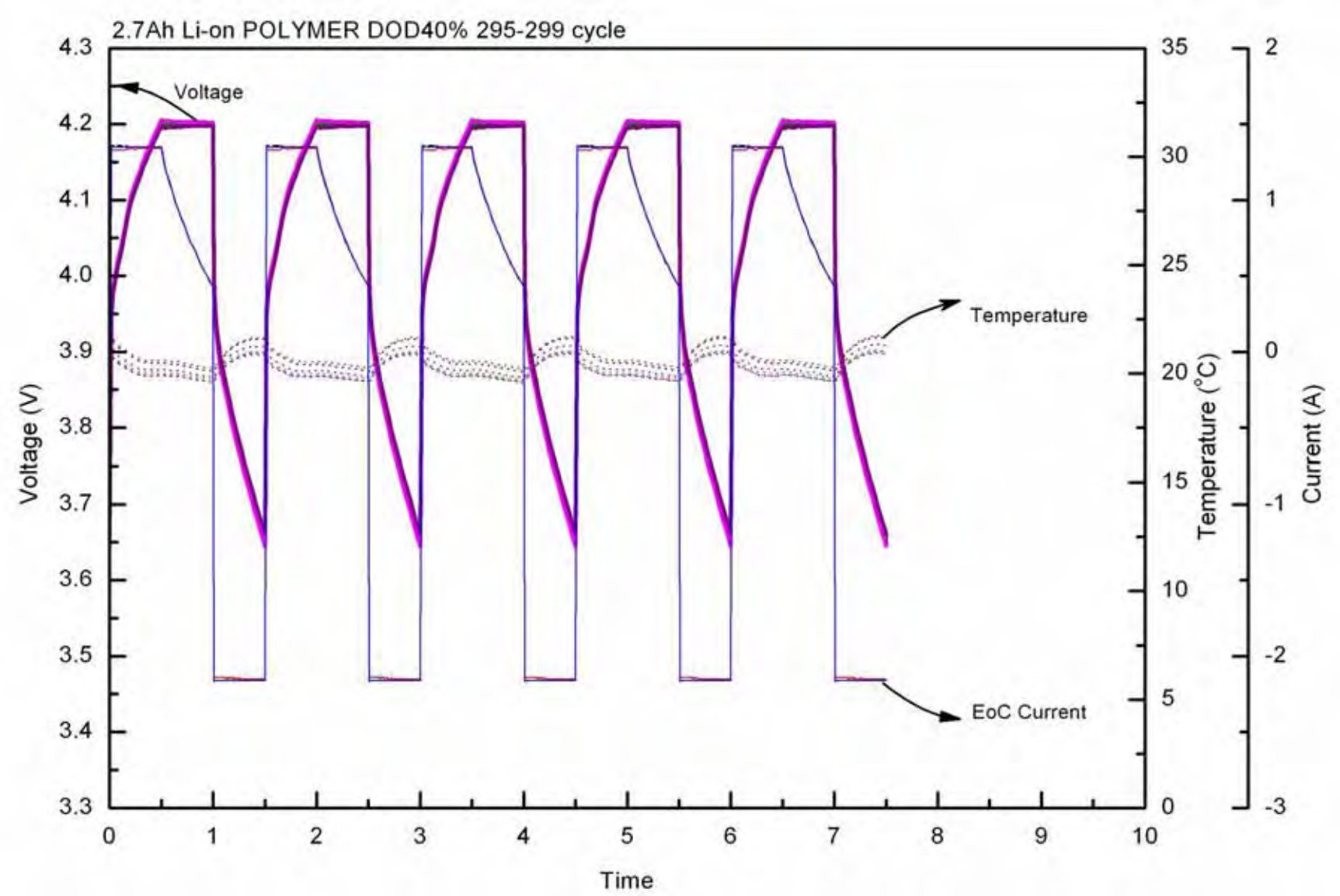
Group A	Group B	Group C
2 cells with resemblant to 1. Capacity 2. Impedance different 3. Self-Discharge rate	2 cells with resemblant to 2. Impedance 3. Self-Discharge rate different 1. Capacity	2 cells with resemblant to 1. Capacity 3. Self-Discharge rate different 2. Impedance

40%DOD life cycling test connected in 2s3p

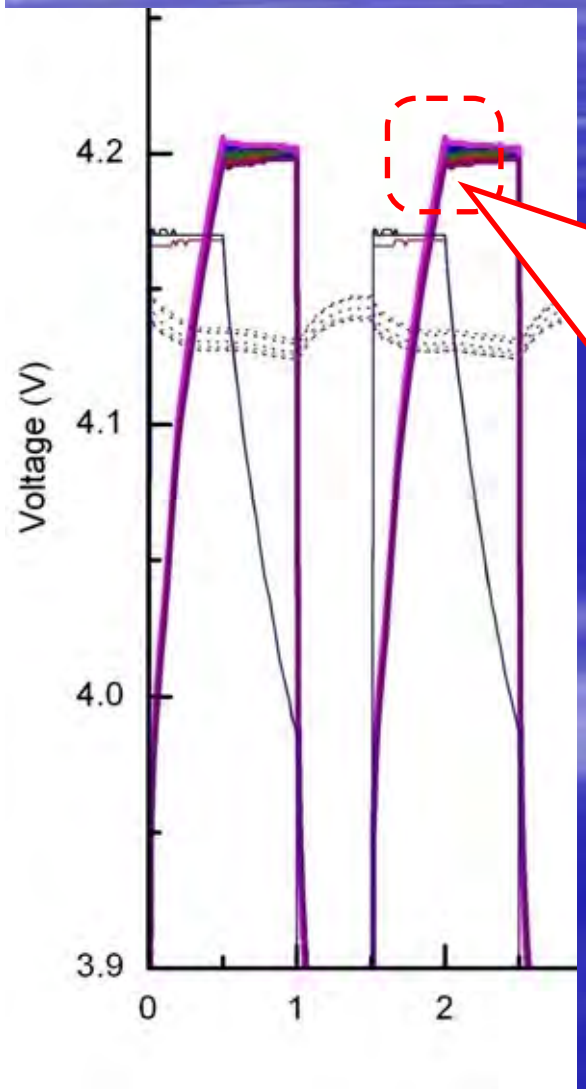
40%DOD Life Cycling Test

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

Progressed 300 cycles, varied slightly



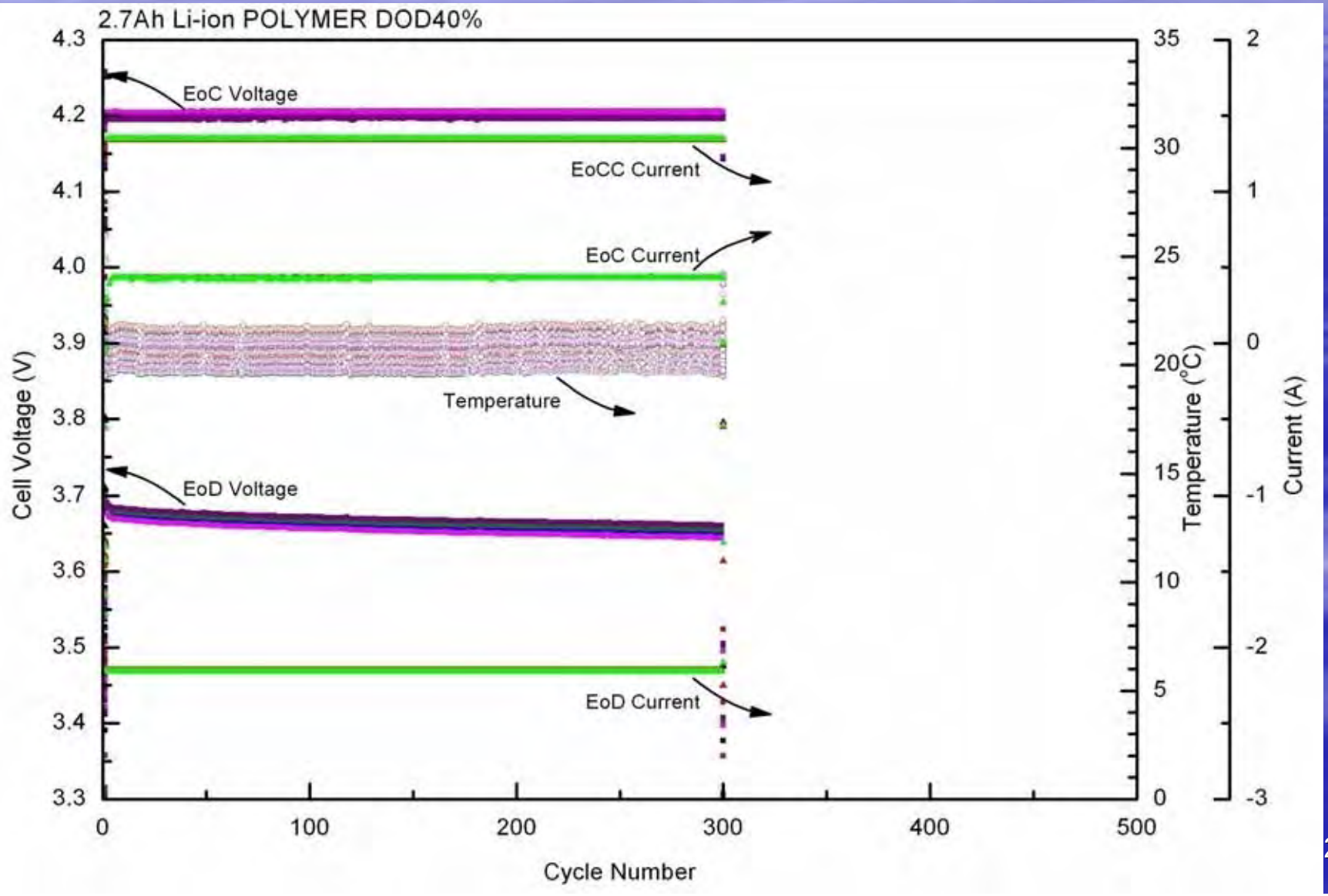
Voltage evaluation at EoCC, most variation



C: different Impedance
A: different Self-Discharge rate
B: different Capacity
B: different Capacity
A: different Self-Discharge rate
C: different Impedance

9 mV
6 mV
2 mV

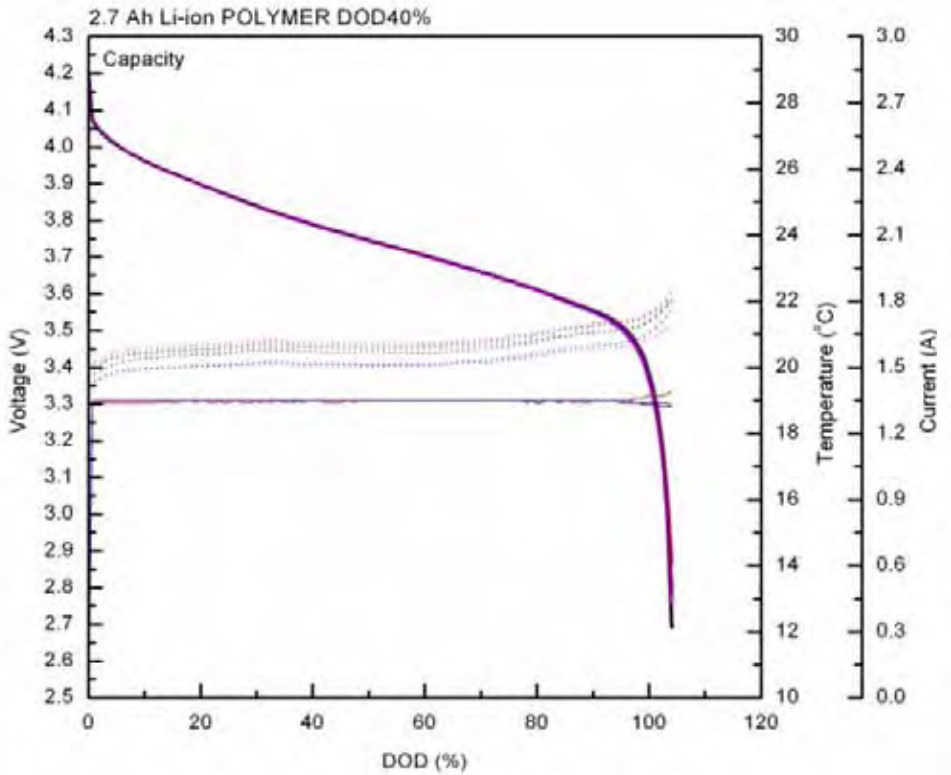
Voltage variation has NOT increased by cycles yet

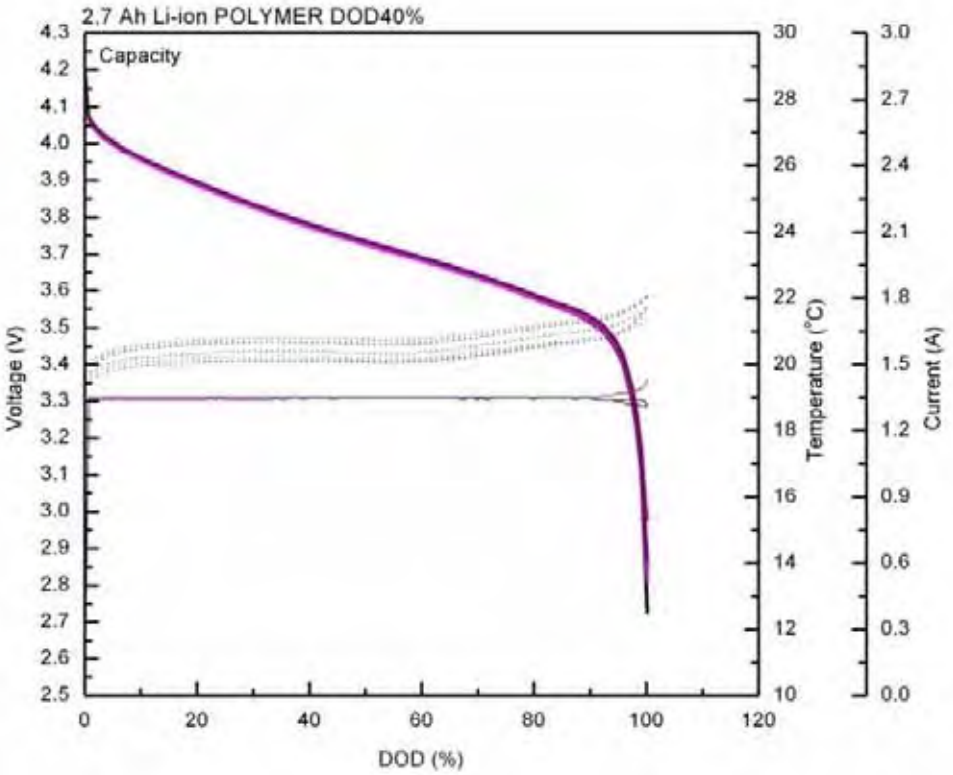


40%DOD Life Cycling Test

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

Initial Capacity → Capacity after 300 cycles





Voltage Variation at 50%DOD increased (2 mV → 10 mV)
Capacity Fade (2.79 Ah → 2.70 Ah)

4. Conclusions

To use commercially available lithium-ion cells on small satellites;

- We studied the basic characteristic of 7 kinds of the commercially available lithium-ion cells, and made them to the database for model cell selection.
- We tested lithium-ion polymer cells, and compared parameters. We analyzed which parameter makes cells' variations most by life cycling test. We'll continue the test and identify it.

Furthermore, we'll evaluate property of battery assembly.