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Performance of the Lithium-Ion Secondary Cells Targeting Lunar and Planetary Missions

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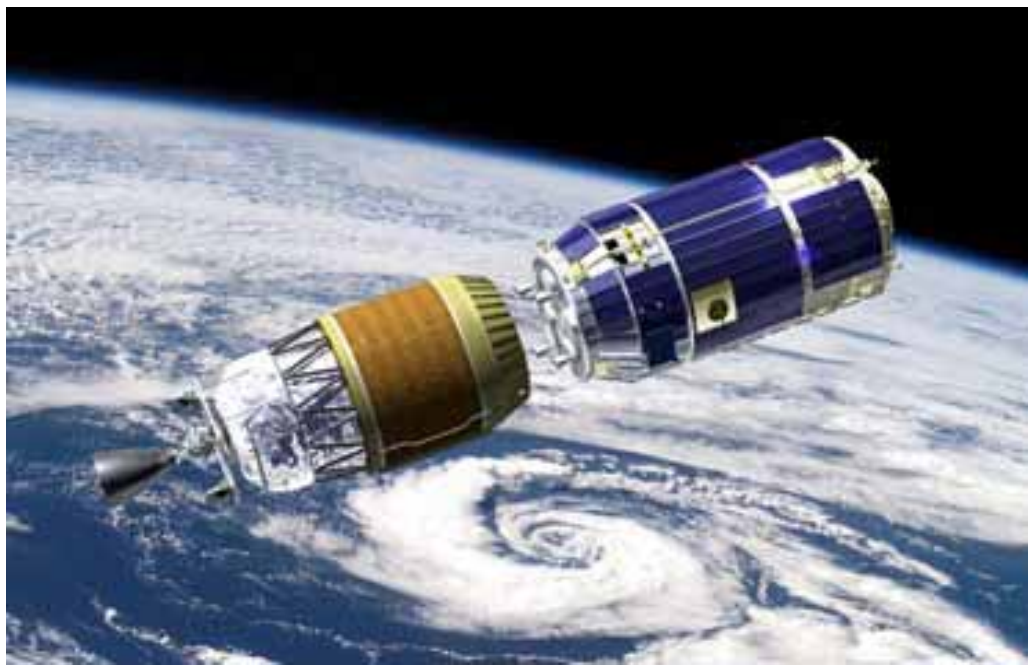
1-1.Development of the lithium-ion secondary cell for HTV

HTV (H-II Transfer Vehicle) is a cargo to supply things to the International Space Station. The diameter of the spacecraft is approx. 4 m, and the height is approx. 10 m.
It carries instruments for the experiments, food, clothes, etc. Maximum weight of the cargo is 6 t. In order to realize this mission, HTV project of the Japan Aerospace Exploration Agency developed lithium-ion secondary cell with high energy density.



1-2. Purpose of this study

JAXA is developing small and light weight power system to enhance operational ability and achieve high reliability of spacecrafts. Especially, Lithium-ion secondary battery is key item as a energy storage device. And it has been started to use in practical missions.
In this study, we evaluated 200Ah class Lithium-ion cell which has been developed for HTV and shows the largest specific energy among available cells for Lunar missions.

Table. Thermal condition on the surface of the Moon.

	Polar area	Middle/Low latitude area
Day-time temperature	220 K	400 K
Night-time temperature	110 K	110 K
Night time	122 hours	354 hours

Generally, Lithium-ion cell is used in the range of around 0 to 30 deg.C. If we keep this higher limit at the Lunar mission to avoid fast degradation, the lower temperature becomes very low.

1-3. Evaluation points

- To survive eclipse(night) of the moon with a battery system, it is important to consider battery power system operation condition with data about high temperature storage ability during solstice and low temperature discharge performance during eclipse.
- The tests have been performed with available highest specific energy space qualified Lithium-ion secondary cell.
  - Understand high temperature storage ability of the cell for 354hr solstice period.
  - Understand low temperature discharge performance of the cell for eclipse operation.

2. Specification of the cell

HTV P-BAT cell (LFR200-101)

Terms	Specification	Conditions
Size / mm	165×50×263	Without the terminals.
Volume / L	2.03	Without the terminals.
Mass / g	4550	-
Discharged capacity / Ah	230	4.2 V charged at 15deg.C
	200	4.1 V discharged at 15deg.C
Averaged discharge voltage / V	3.8	15 A discharged at 15deg.C
Energy density / Wh・kg-1	192	4.2 V charged at 15deg.C

Fig. Photograph of the cell (LFR200-101)

3. Evaluation tests for Lunar missions

3-1. Simulated Lunar operation test condition

	Operation		Note
Solstice	Stand-by at 50 deg.C for 354hr	Cell1: Full charged state	No thruster power required In this test, we compared left two conditions.
		Cell2: 10%SOC stand-by and charged just before Eclipse	
Eclipse	Discharge at –20 deg.C C/50(=4A) is used as a acceleration test with negligible heat effect though the practical discharge rate will be C/354(=0.6Amp) in the mission.		Temperature is set –20 deg.C to reduce power for heater Discharge profile data was confirmed until 2.75V cut-off.

3-2. Test flow

Initial inspection
Dimensions, Mass
Capacity (std)
AC Impedance(1kHz)

↓

Capacity check

1st cycle: 4.20V charge at 15deg.C → 15A discharge (2.75V cut) at 15 deg.C
2nd cycle: 4.10V charge at 15deg.C → 30A discharge (2.75V cut) at 15 deg.C
3rd cycle: 4.10V charge at 15deg.C → 15A discharge (2.75V cut) at 15 deg.C
4th cycle: 4.10V charge at 15deg.C → 4A discharge (2.75V cut) at -20 deg.C

Repeat

↓

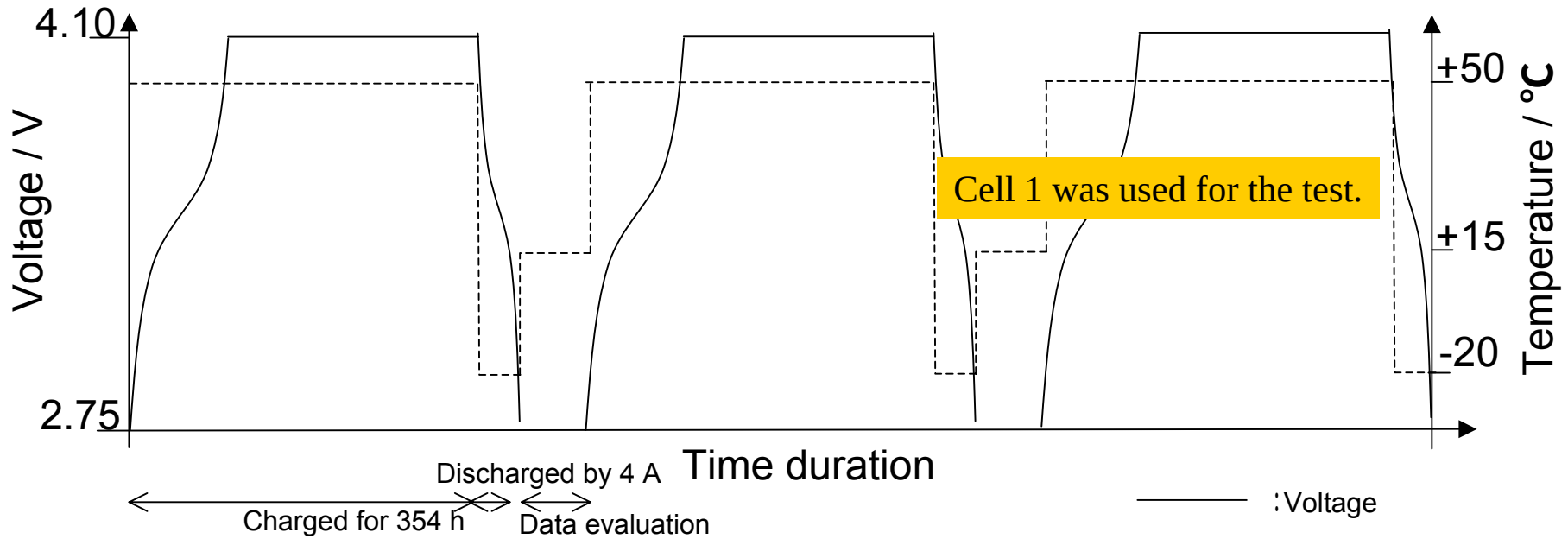
Simulated Lunar operation test

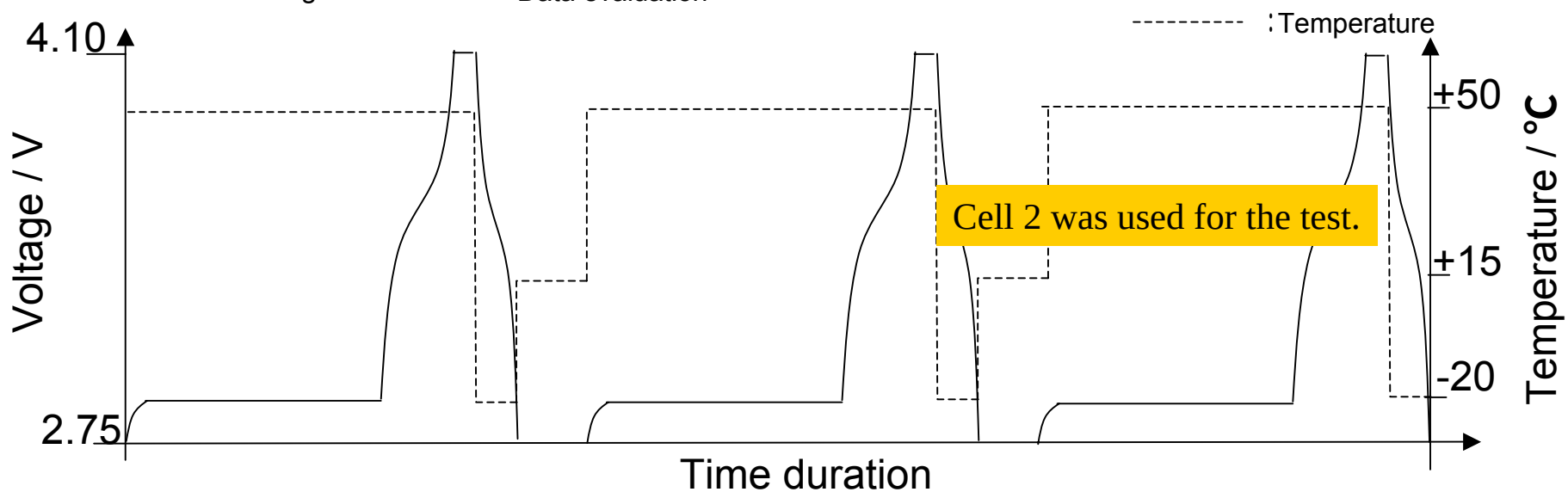
Cell1: Charged state at solstice 4.10V at 50 deg.C
→ Discharge at eclipse 4A to 2.75V at –20deg.C

Cell2: Discharge state at solstice at 50 deg.C , 4.10V charge just before eclipse
→ Discharge at eclipse 4A to 2.75V at –20deg.C

Note: Charge voltage 4.10V was chosen for possible longer mission requirements
Discharge current 4A was chosen as a highest current within a range which won't results cell temperature rise.

Charge and Discharge profile





3-3. Results

Initial inspection

Item	Cell 1	Cell 2
Dimension / mm	Width: 165.0 Thickness: 49.9 Height: 263.4	Width: 164.9 Thickness: 49.9 Height: 263.6
Mass / g	4521	4536
Capacity / Ah*	224.9	228.8
AC Impedance (1kHz) at 10%SOC / m-ohm	0.51	0.51

<u>*Standard capacity check condition</u>
Charge: 20A/4.20V (CC/CV) 16hr at 25 deg.C
Discharge: 15A 2.75V at 15 deg.C

Initial performance of the cell

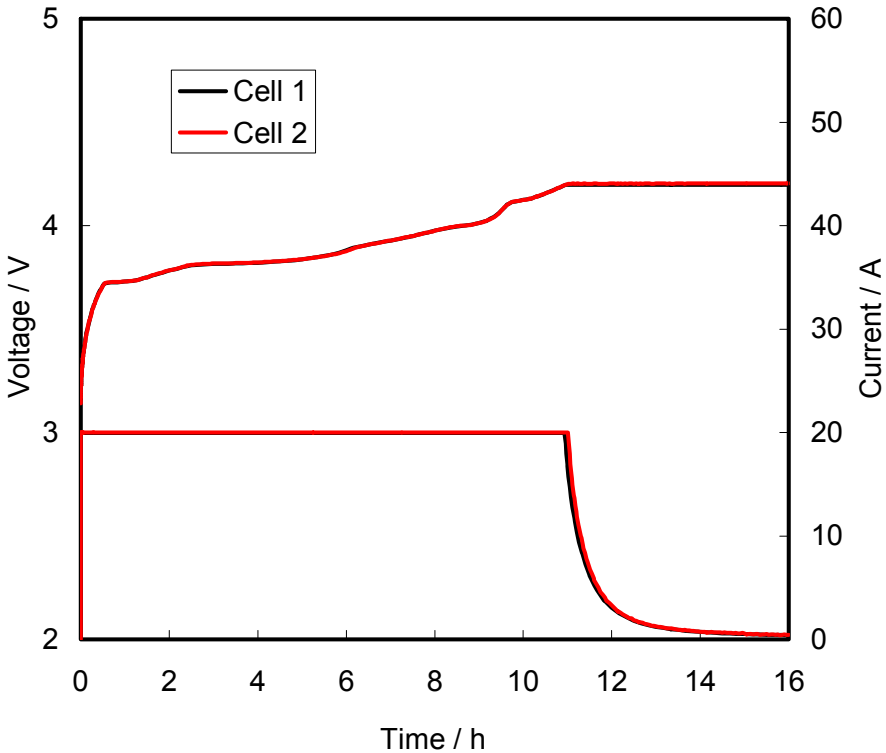


Fig. Charge curve of the LFR200-101 cell

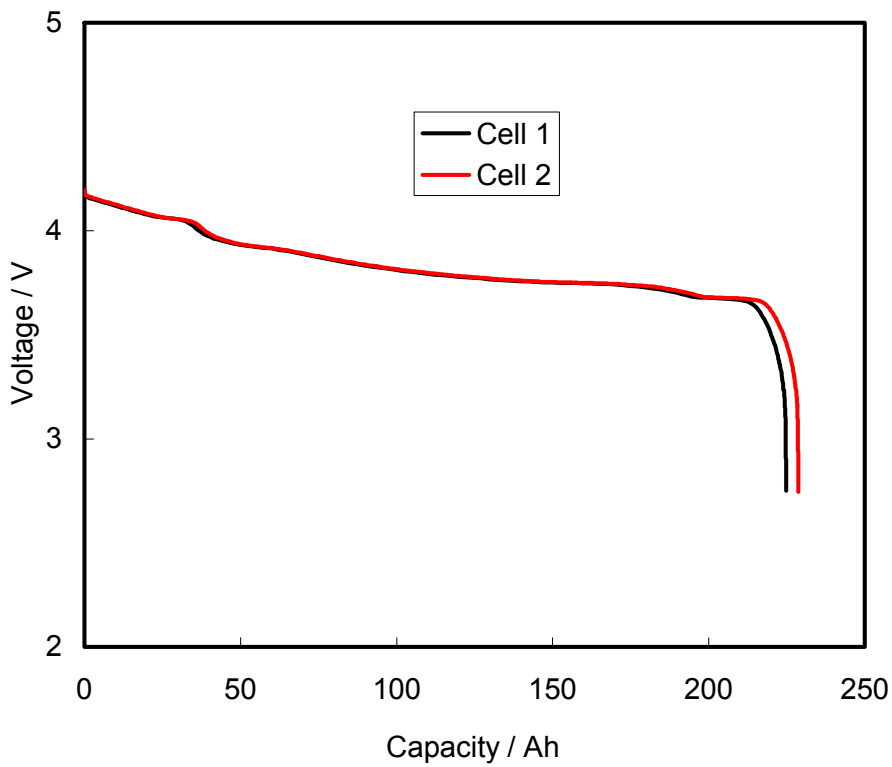


Fig. Discharge curve of the LFR200-101 Cell

Charged by 20 A to 4.20 V spending for 16 hours at 25deg.C.
Discharged by 15 A to 2.75 V at 15deg.C.

Voltage profiles at eclipse discharge

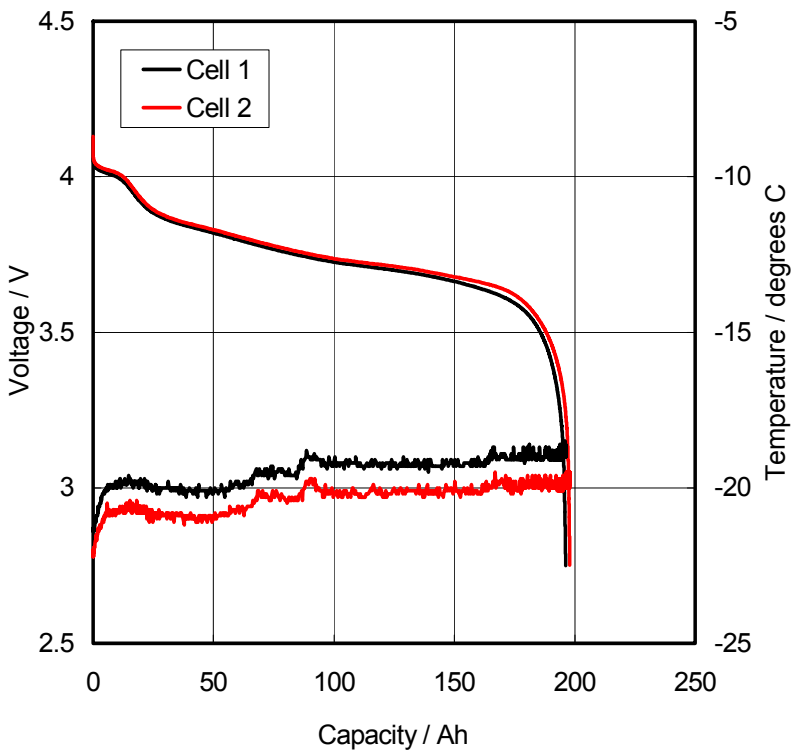


Fig. Discharge capability during the first pattern

Discharged by 4A to 2.75V at -20℃.

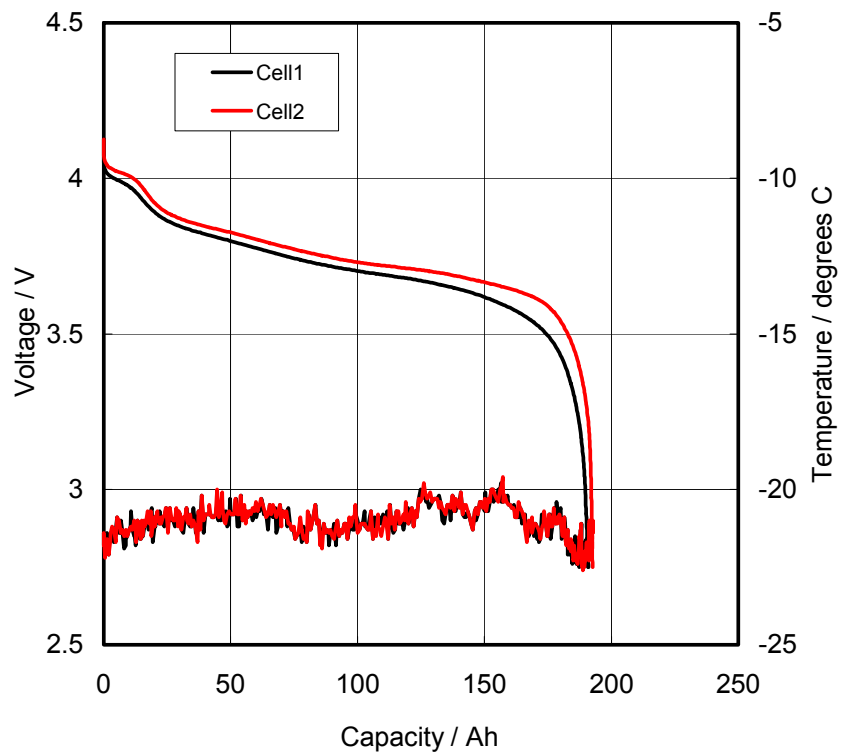


Fig. Discharge capability during the second pattern

Discharged by 4A to 2.75V at -20℃.

Voltage profiles at eclipse discharge (continued)

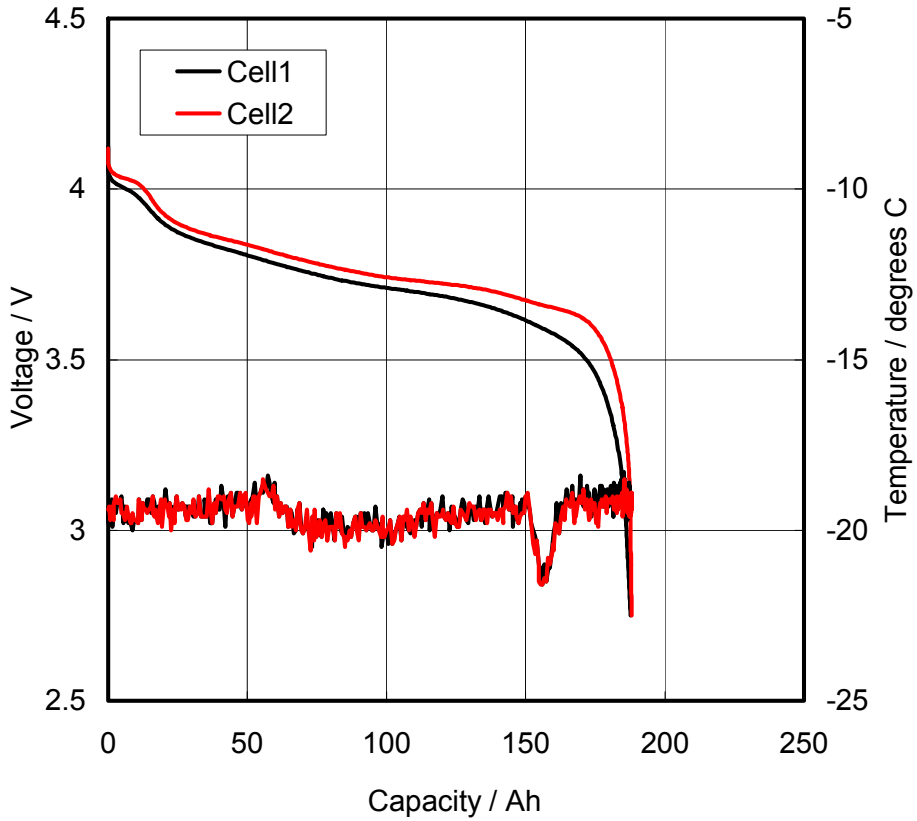


Fig. Discharge capability during the third pattern

Discharged by 4A to 2.75V at -20℃.

The 'Cell 2' showed slightly higher voltage during the discharge, while the difference of the discharged capacity was quite negligible.

* The Voltage after the discharge of 150 Ah was 3.616 V for 'Cell 1' and 3.674 V for 'Cell 2.'
(The difference was only 58 mV.)

Eclipse discharge trend

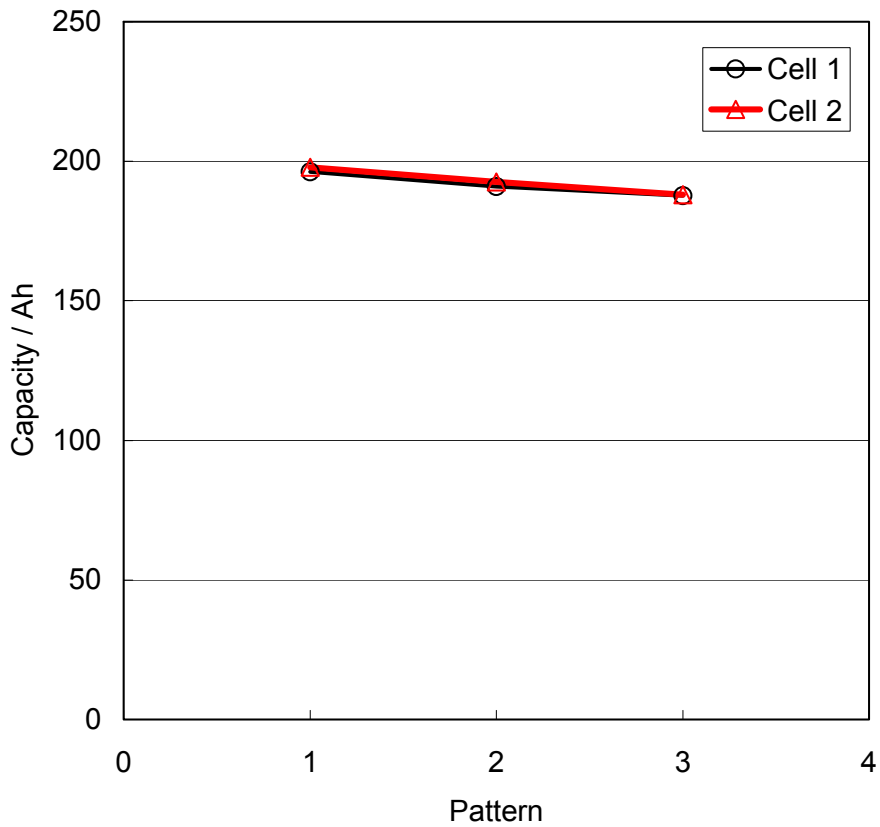


Fig. Eclipse discharge capacity trend

<u>Test condition</u>
Discharge: 4A to 2.75V at –20 deg.C

Capacity check test results (The first cycle after the Lunar simulation pattern)

Result: No significant difference between Cell1 and Cell2 at 15 deg.C

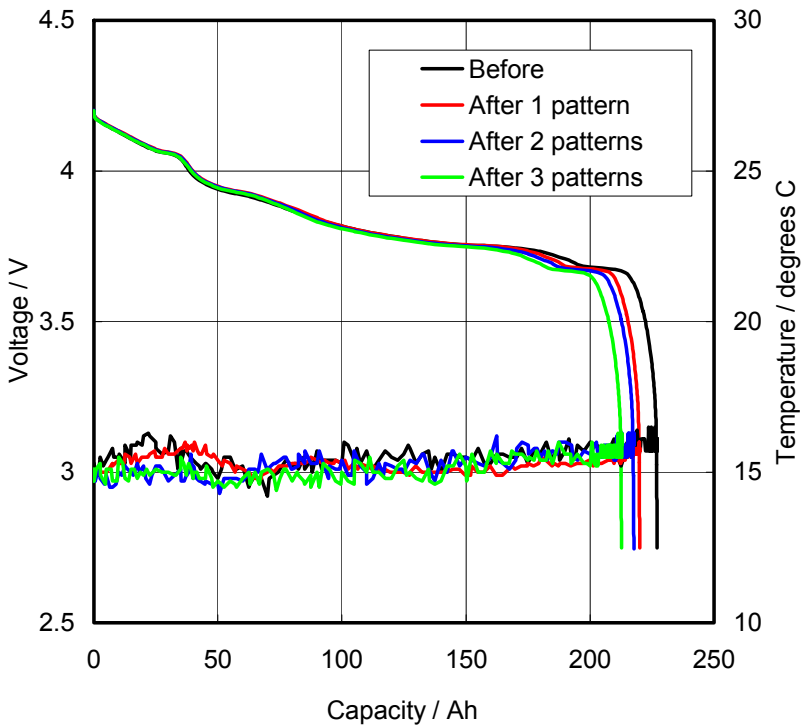


Fig. Discharge profile of Cell1

<u>Test condition</u>
Charge: 20A/4.20V (CC/CV) 16hr at 15deg.C
Discharge: 15A to 2.75V at 15deg.C

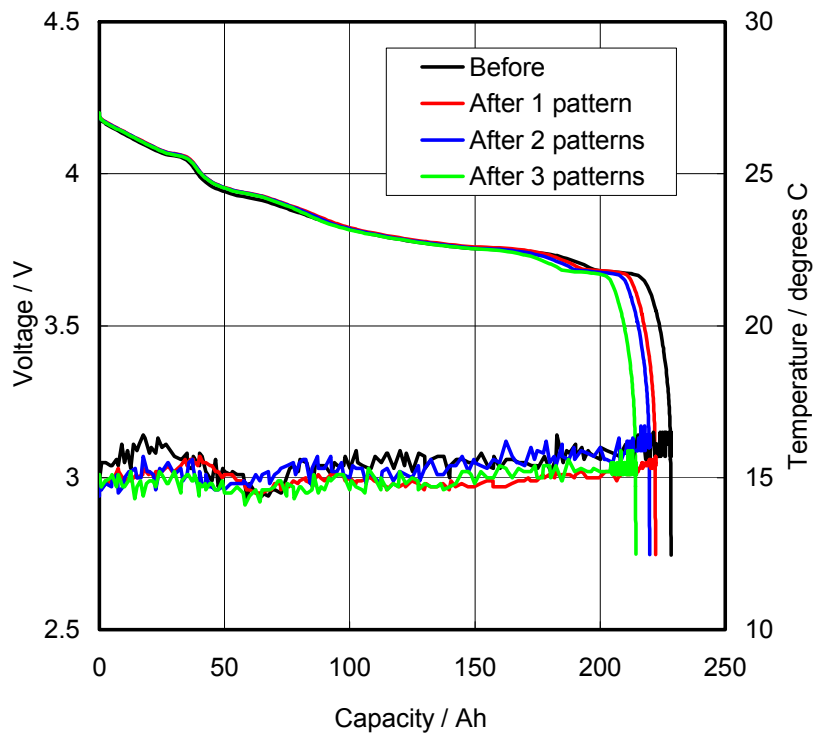


Fig. Discharge profile of Cell2

<u>Test condition</u>
Charge: 20A/4.20V (CC/CV) 16hr at 15deg.C
Discharge: 15A to 2.75V at 15deg.C

Capacity trend at capacity check discharge

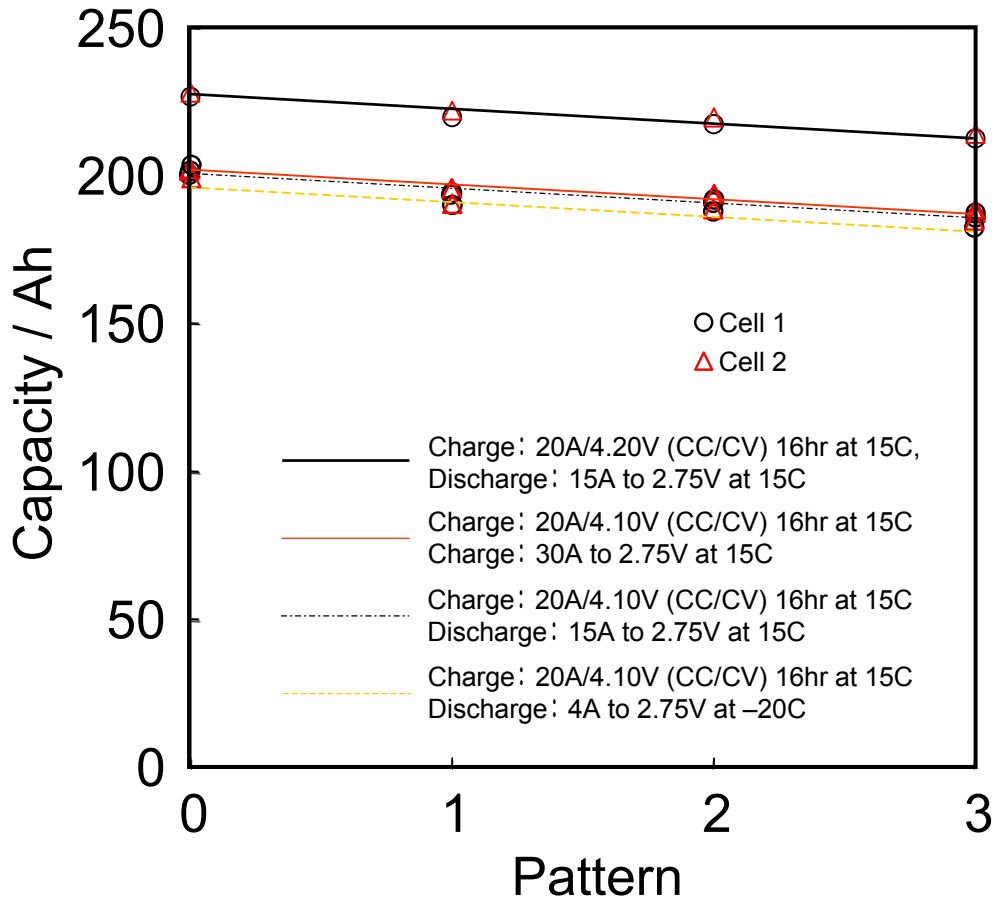


Fig. Capacity trend of the capacity check discharge after Lunar simulation pattern

Result: Capacity check cycles are performed to evaluate the effect of the Lunar simulated condition. However, no significant performance degradation observed.

DC resistance measurement result

(DCR was calculated the voltage difference of the 2nd cycle and 3rd cycle at 15 deg.C)

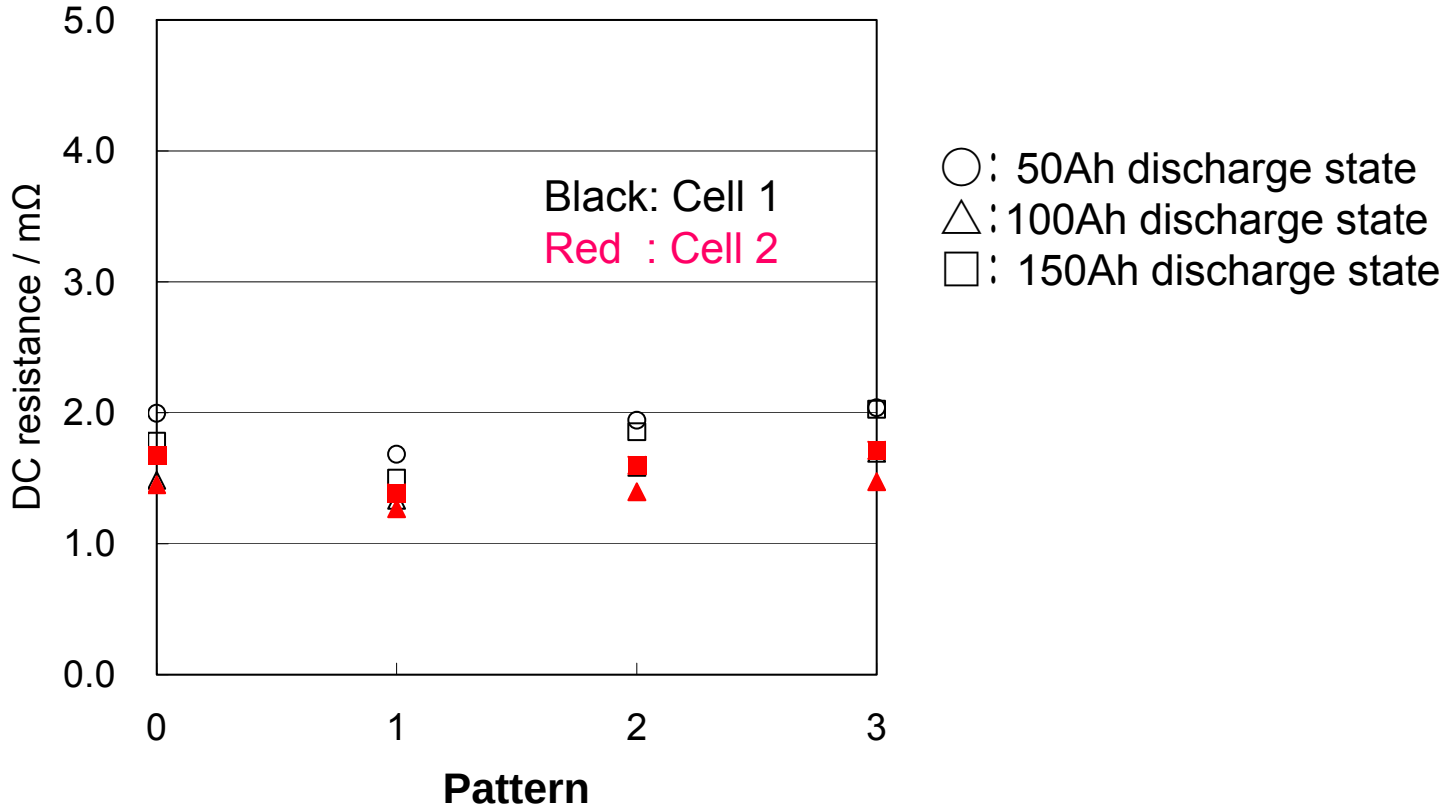


Fig. DCR trend after each Lunar simulated pattern

Result: No significant difference at DCR trend

4. Summary

The lithium-ion secondary cells developed for the HTV project were tested simulating lunar conditions.
Two different cells were prepared. ‘Cell 1’ maintained high SOC during the day-time, and ‘Cell 2’ maintained low SOC during day-time and fully charged just before the night-time.
The voltage of ‘Cell 1’ showed slightly lower than ‘Cell 2’, while the difference was quite small.
The experiments revealed the applicability of the cell to the lunar programs.