# Development of Generation 3 Large-format Li-ion Cells for Space Applications

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**Abstract**

GS Yuasa Technology (GYT) has evaluated large−format prototype 110 Ah class generation 3 cells for space application since 2008. It has been confirmed that the cells show the advantages of higher energy and longer cycle life compared to generation 2 cells. The cells are capable of supplying power for more than 2,000 cycles in geostationary earth orbit (GEO) mission use, and 40,000 cycles in low earth orbit (LEO) mission use. Japan Aerospace Exploration Agency (JAXA) and GYT have therefore newly qualified 42, 55, and 150 Ah class cells. As the results of qualification testing, the cells have demonstrated tough mechanical environmental durability in addition to superior discharge and life performance.

*Key words* : Space−qualified Li−ion cells ; High energy ; Long life ; Mechanical environmental durability

## 1 Introduction

GS Yuasa Technology (GYT) has first fixed the design of generation 1 Li−ion cells for space use in 1998, and then done it of generation 2 in 1999. GYT has manufactured thousands of cells since then, and they have been used for more than 50 satellites. It is notable that the cells have worked without any failures on orbit. In addition to its high quality performance, the stable configuration control of GYT has been highly appreciated by Japan Aerospace Exploration Agency (JAXA). As a result, 50 and 100 Ah class generation 2 cells have been qualified as its one of reliable space components in 2008.[1] The cells will be used to power JAXA satellites of ALOS−2, SPRINT A, ASTRO−H, and GCOM−C1.

GYT has also started the research and development of generation 3 cells to meet the customers' requests of higher energy and longer life performance since 2008. The evolution of GYT space cells is summarized in Table 1. The prototype 110 Ah cells have shown advantages of higher discharge voltage and less than half capacity loss in long term cycle life tests com-

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Table 1 Evolution of GYT Li−ion cells for space use.

| Generation | 1* | 2* | 3 |
|---|---|---|---|
| First qualified in / year | 1998 | 1999 | 2009 |
| Dimensions(H x W x T) / mm | 208 x 130 x 50 | | |
| BOL nominal capacity / Ah | 110 | 110 | 122 |
| BOL rated capacity / Ah | 100 | 100 | 110 |
| Nominal voltage / V | 3.7 | 3.7 | 3.7 |
| Mass / kg | 2.79 | 2.79 | 2.77 |
| Energy density / Wh/kg | 146 | 146 | 163 |

* The difference of generation 1 and 2 is electrolyte solution. Genaration 2 shows better life performance.

pared to generation 2 cells, as introduced in the previous GS Yuasa Technical report.[2] This paper reports the latest information of the progress of cycle life testing. Furthermore, JAXA and GYT have newly qualified 42, 55, and 150 Ah class generation 3 cells. Multiple rate discharge performance and mechanical environmental durability of these cells are also described in this paper.

## 2 Cell specification overview

Table 2 shows the specifications of generation 3 space qualified Li-ion cells. All the cells use the same chemistry and electrode design, while the dimensions are different. They show almost the same rate performance regardless of the size.

The 42, 55, and 110 Ah cells are evolutionary version of 35, 50, and 100 Ah generation 2 cells, respectively. Their dimensions were not changed along with advance of generation. It makes it easier for existing battery assemblers to use generation 3 cells.

## 3 Qualification test conditions

### 3.1 Multiple discharge rate test

In order to evaluate discharge performance, 150 Ah cells were discharged at multiple rates, according to the following condition.

Charge: 0.1 CA, 4.10 V, CC/CV, 15 hours

Discharge: 0.3, 0.6, 0.9, and 1.2 CA to 2.75V

Temperature: 15℃

Table 2 Specifications of generation 3 cells.

| Model | | JMG042 | JMG055 | JMG110 | JMG150 |
|---|---|---|---|---|---|
| Nominal capacity / Ah | | 46 | 61 | 122 | 160 |
| Rated capacity / Ah | | 42 | 55 | 110 | 150 |
| Nominal voltage / V | | 3.7 | 3.7 | 3.7 | 3.7 |
| Mass / kg | | 1.1 | 1.52 | 2.77 | 3.53 |
| Energy density / Wh/kg | | 155 | 148 | 163 | 168 |
| Dimensions / mm | H* | 159 | 131 | 208 | 271 |
| | W | 98 | 130 | 130 | 130 |
| | T | 37 | 50 | 50 | 50 |
| Life | GEO** | 20 years, 2,000 cycles | | | |
| | LEO*** | 7 years, 40,000 cycles | | | |

* Without terminal bolts
** GEO: Geostationary Earth Orbit
*** LEO: Low Earth Orbit

### 3.2 Life test

In order to evaluate the life performance in short term, the cells were subjected to DOD 100% cycle life testing as an accelerated test. The cells were also subjected to DOD 80% and DOD 25% cycle life testing to confirm the performance for GEO and LEO uses, respectively. Each life test condition is shown below.

(1) DOD 100% cycle life test

Charge: 0.5 CA, 4.10 V, CC/CV, 4 hours

Discharge: 1 CA* or 0.91 CA** to 2.75 V

Temperature: 25℃

* For 42, 55, and 150 Ah cells

** For prototype 110 Ah cells

(2) DOD 80% cycle life test

This test was performed on 55 and prototype 110 Ah cells.

Charge: 0.2 CA, 4.10 V, CC/CV, 11.4 hours*

Discharge: 0.67 CA for 1.2 hours

Temperature: 15℃

* Semi-accelerated condition of GEO mission use

(3) DOD 25% cycle life test

Charge: 0.3 CA, 4.10 V, CC/CV, 1 hour

Discharge: 0.5 CA for 0.5 hours

Temperature: 15℃

Prior to DOD 80% and DOD 25% cycle life tests, 42, 55, and 150 Ah cells were subjected to environments described in the following paragraph.

### 3.3 Mechanical environmental test

In order to evaluate mechanical environmental durability during the launch, the cells were subjected to sine and random vibrations, shock, and acceleration tests. Their conditions are shown in Tables 3 to 6, respectively. During the testing, the cells were discharged at 0.25 CA in consideration the case that they supply power to the satellite components while in the launch.

## 4 Results and discussion

The cells demonstrated superior life performance together with stable discharge performance and tough mechanical environmental durability. Their details are described in this paragraph.

### 4.1 Discharge rate performance

Fig. 1 shows multiple rates discharge profiles for

150 Ah cells. It shows that discharge voltage change caused by the rate increase is small. Furthermore, discharge capacity does not depend on the rate. This means the cells have a user−friendly discharge performance.

### 4.2 Life performance

(1) DOD 100% cycle life test

Fig. 2 shows DOD 100% cycle life performance of the cells. The average capacity loss ratio of the cells is only 12.6% after long cycling of 2,000 cycles. It's notable that prototype 110 Ah cells show no traces of significant degradation even after 5,000 cycles. Other generation 3 cells show almost the same capacity trend with that of 110 Ah cells.

(2) DOD 80% cycle life test

Fig. 3 shows changes in charge and discharge characteristics for prototype 110 Ah generation 3 cells. It

Table 3　Sine vibration test condition.

| Axis | Frequency / Hz | Levels |
|---|---|---|
| X, Y, Z | 5 − 27.9 | 6.4 mm (Single Amplitude) |
| | 27.9 − 100 | 20 G |

＊Sweep rate: 2 octave / min

Table 4　Random vibration test condition.

| Axis | Frequency / Hz | Levels | Grms |
|---|---|---|---|
| X, Y, Z | 20 − 58 | +6 dB/octave | 23.63 |
| | 58 − 700 | 0.5 $g^2$/Hz | |
| | 700 − 2,000 | −6 dB/octave | |

＊Testing time: 3 minutes per axis

Table 5　Shock test condition.

(a) 150 Ah class cells

| Axis | Frequency / Hz | Levels / G |
|---|---|---|
| ± X, ± Y, ± Z | 100 | 20 |
| | 1,000 | 1,300 |
| | 2,000 − 10,000 | 3,400 |

(b) 42 and 55 Ah class cells

| Axis | Frequency / Hz | Levels |
|---|---|---|
| ± X, ± Y, ± Z | 200 | 40 G |
| | 200 − 2,000 | +9.296 dB/octave |
| | 2,000 − 7,000 | 1,400 G |

＊Number of shock is 3 per axis, 18 in total

Table 6　Acceleration test condition.

(a) 150 Ah class cells

| Axis | Levels / G |
|---|---|
| ± X, ± Y, ± Z | 30 |

(b) 42 and 55 Ah class cells

| Axis | Levels / G |
|---|---|
| ± X, ± Y, ± Z | 25 |

＊Testing time: 5 minutes per axis

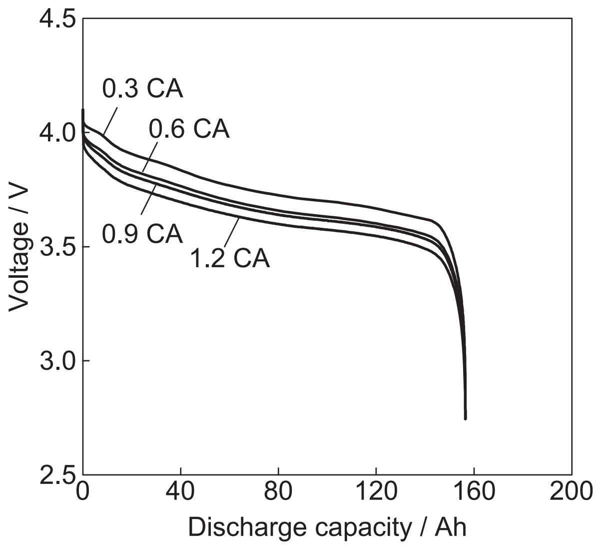


Fig. 1　Multiple rates discharge profiles of 150 Ah cells. The cells were discharged at 0.3, 0.6, 0.9, and 1.2 CA at 15℃ after charged at 0.1 CA to 4.10 V followed by constant voltage for 15 hours in total.

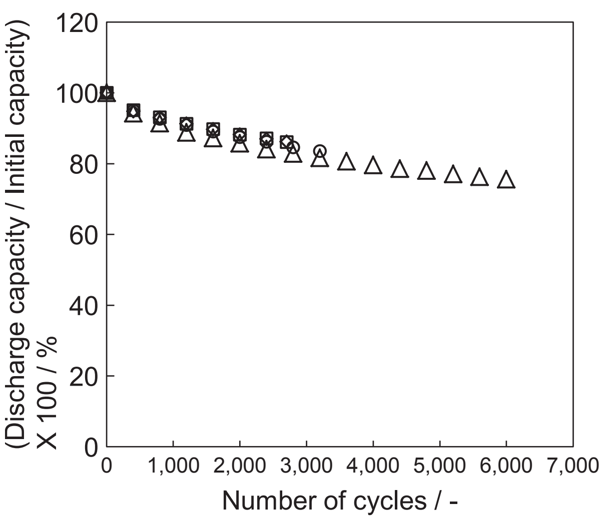


Fig. 2　Changes in discharge capacity during DOD 100% cycle life test for prototype 110 Ah (△), 42 Ah (□), 55 Ah (◇), and 150 Ah (○) cells at 25℃. The cells were discharged at 0.91 CA (prototype 110 Ah cells) or 1 CA (42 Ah, 55 Ah and 150 Ah cells) to 2.75 V after charged at 0.5 CA to 4.10 V followed by constant voltage for 4 hours in total.

shows almost no characteristics change over 2,000 cycles. Decrease of end of discharge voltage (EoDV) is only 44 mV. Fig. 4 shows changes in full discharge capacity of the cells that has been periodically confirmed. It shows that the cells still deliver 106 Ah even after 2,000 cycles. Required capacity for DOD 80% is 88 Ah. Therefore the cells still have sufficient energy margin to continue DOD 80% cycling. Fig. 5 shows predicted changes in full discharge capacity retention and EoDV for generation 3 cells that were calculated by the life model.[3, 4] It shows the cells still have a sufficient capability to power the satellite at 4,000 cycles.

(3) DOD 25% cycle life test

Fig. 6 shows changes in charge and discharge characteristics for prototype 110 Ah generation 3 cells. The cells show similar voltage characteristics over 20,000 cycles. Fig. 7 shows changes in full discharge capacity of the cells that has been periodically confirmed. It shows that the cells still deliver 106 Ah even after 20,000 cycles. As a result of the life prediction[3, 4], it is confirmed that the cells are capable of supplying power for more than 40,000 cycles as shown in Fig. 8.

### 4.3 Mechanical environmental performance

No abnormal discharge voltage behavior was observed through all the environmental tests. No appearance change and no AC impedance increase were

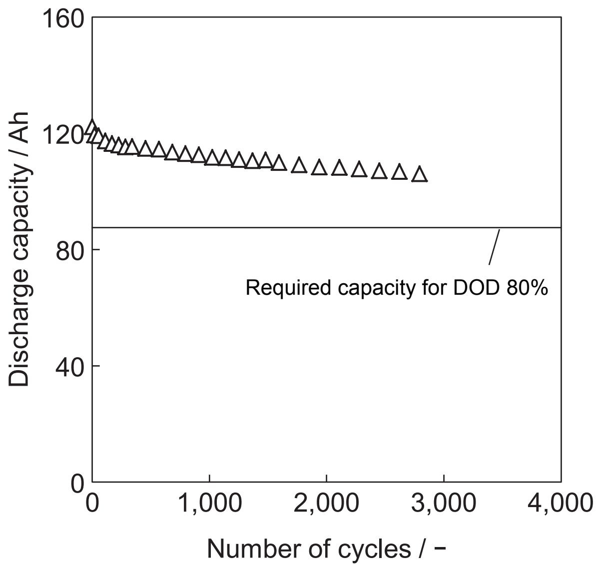


Fig. 4 Changes in full discharge capacity during DOD 80% cycle life tests for prototype 110 Ah cells at 15℃. The discharge capacity is periodically confirmed by discharging at 0.2 CA to 2.75 V after charging at 0.2 CA to 4.10 V followed by constant voltage for 8 hours in total.

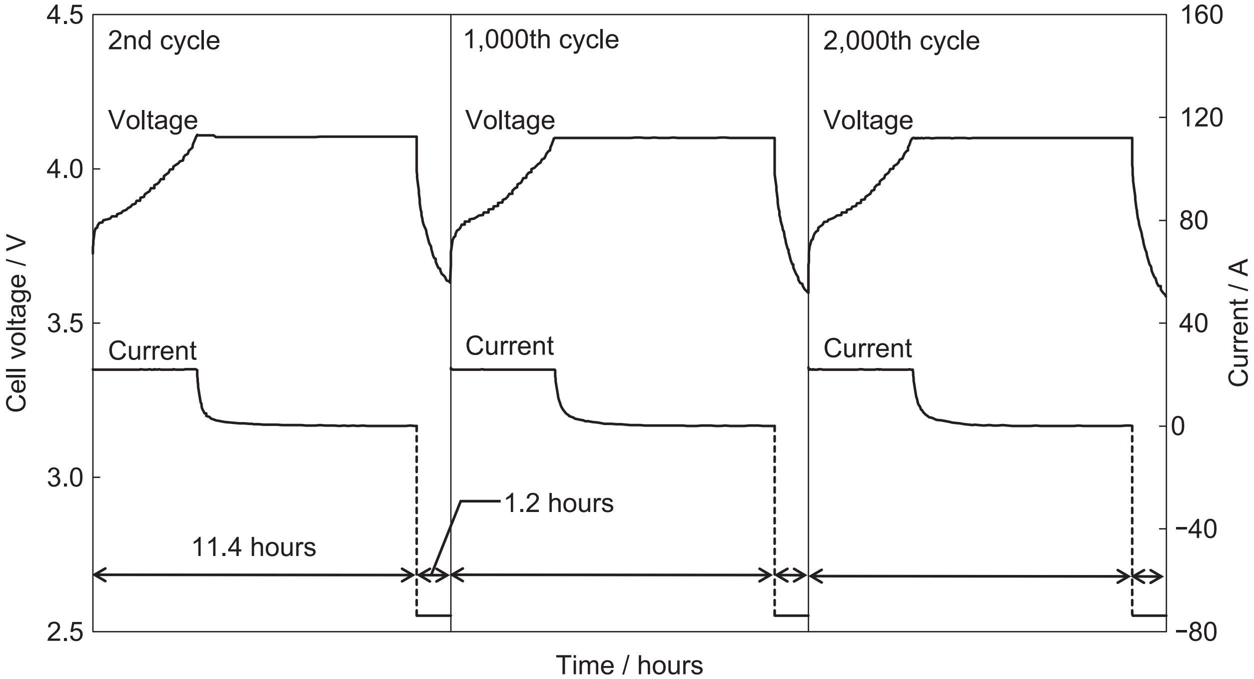


Fig. 3 Changes in charge and discharge characteristics during DOD 80% cycle life tests for prototype 110 Ah cells at 15℃.

also confirmed after the completion of the tests. Fig. 9 shows discharge profiles of 150 Ah cells before and after environmental tests as an example. There is almost no performance change except a slight capacity decrease of less than 1%. It was not caused by the environmental loads, but by the natural calendar effect. From these results, it is clear that generation 3 cells are capable of operating normally on orbit after the launch event.

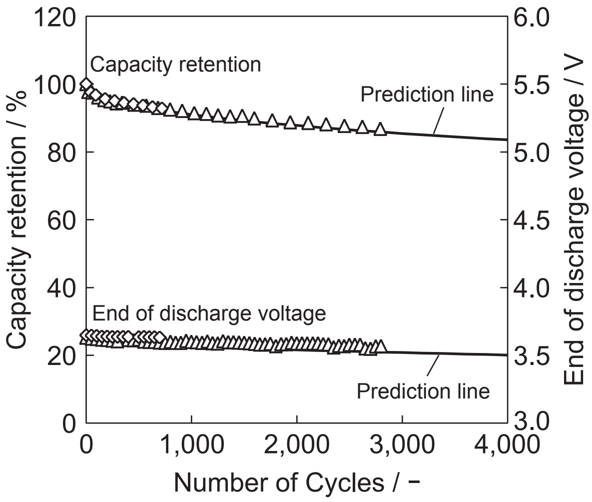


Fig. 5 Predicted changes in discharge capacity and EoDV for generation 3 cells during DOD 80% together with actual test data of prototype 110 Ah (△) and 55 Ah (◇) cells at 15℃.

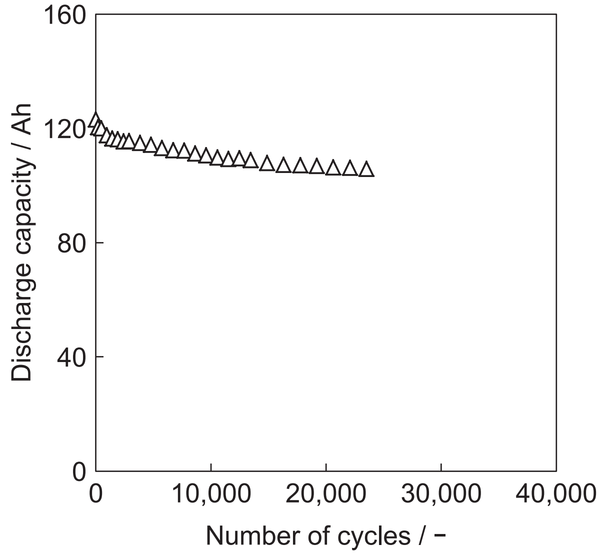


Fig. 7 Changes in full discharge capacity retention during DOD 25% cycle life tests for prototype 110 Ah cells at 15℃. The discharge capacity is periodically confirmed by discharging at 0.2 CA to 2.75 V after charging at 0.2 CA to 4.10 V followed by constant voltage for 8 hours in total.

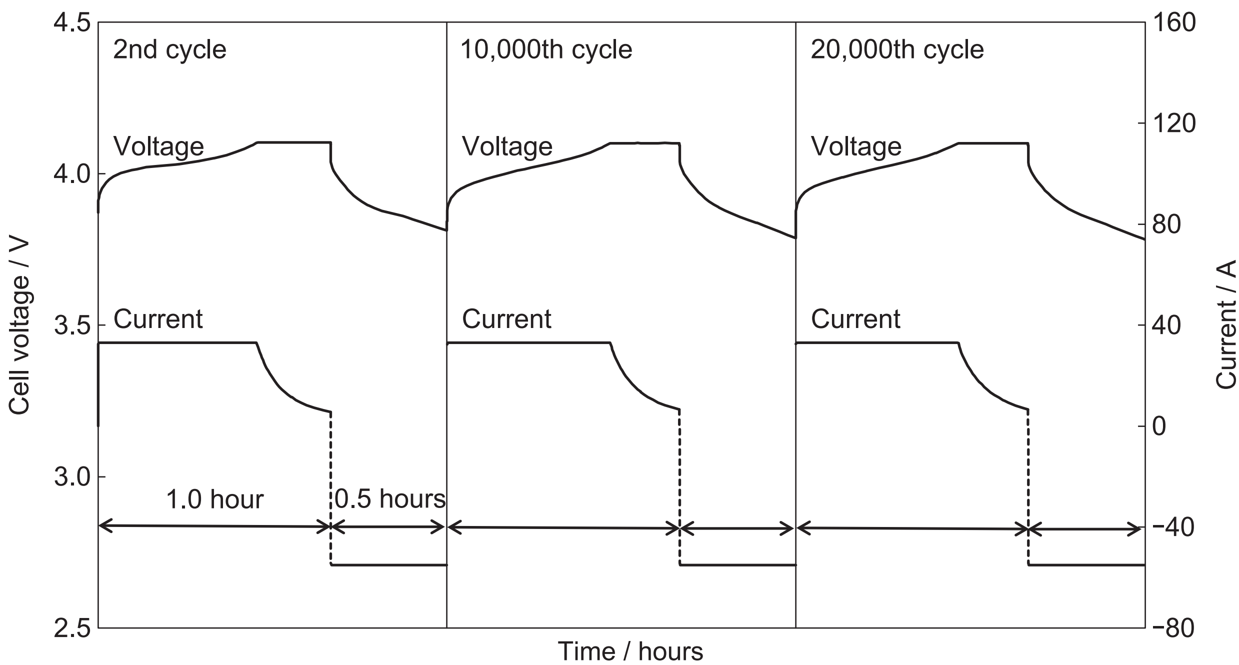


Fig. 6 Changes in charge and discharge characteristics during DOD 25% cycle life tests for prototype 110 Ah cells at 15℃.

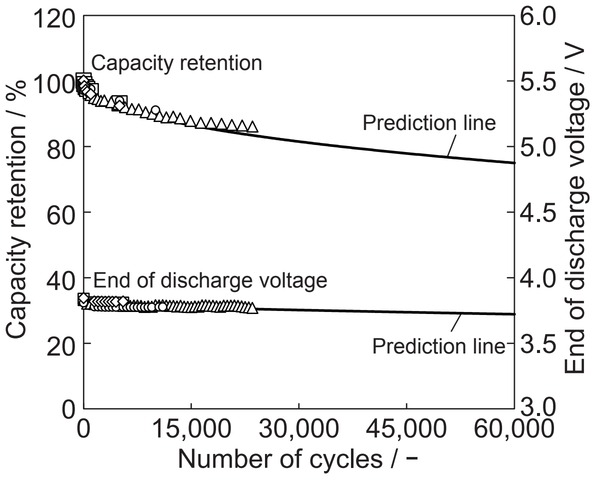


Fig. 8 Predicted changes in discharge capacity and EoDV for generation 3 cells during DOD 25% together with actual test data of prototype 110 Ah (△), 42 Ah (□), 55 Ah (◇), and 150 Ah (○) cells at 15℃.

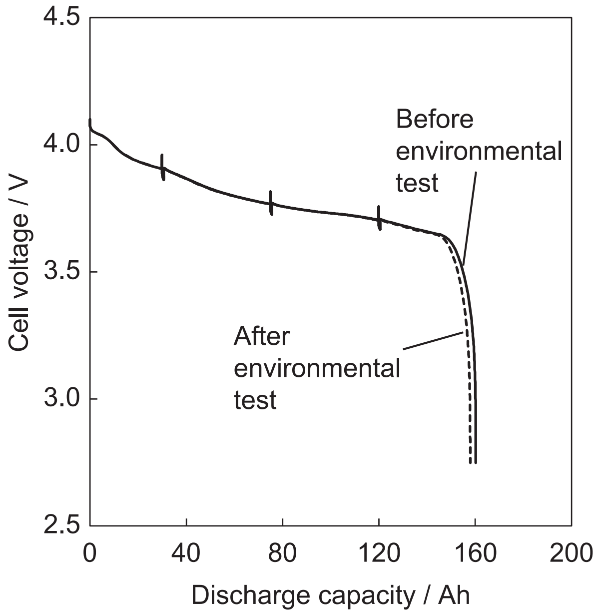


Fig. 9 Representative discharge profiles of 150 Ah cells before and after mechanical environmental tests at 15℃.
The cells were discharged at 0.2 CA to 2.75 V after charged at 0.1 CA to 4.10 V followed by the constant voltage for 15 hours in total. At DOD 20%, 50%, and 80%, the cells were left open for 1 hour and then discharged for 30 seconds at 0.5 CA.

## 5 Conclusions

GYT has evaluated the performance of generation 3 cells. As the results of life testing, it was confirmed the cells have enough capabilities of supplying power to the satellite for more than 2,000 cycles in GEO mission use, and for more than 40,000 cycles in LEO mission use. The cells have also demonstrated superior discharge performance and the tough mechanical environmental durability.

JAXA and GYT have qualified 42, 55, and 150 Ah cells. The qualification of 110 Ah cells is also scheduled to be completed soon. The generation 3 cells will contribute to mass reduction and life extension for the future satellites and the spacecraft.

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